LEARNING TO OPTIMISE READING:

AN EXPLORATORY STUDY OF EYE MOVEMENT TRANSFER ACROSS LANGUAGES

by

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Abstract

This dissertation provides an in-depth analysis of eye movement behaviour during reading in Chinese learners of English as a second language (L2, English), specifically focusing on the unique challenges posed by the divergent orthographic systems of the L1 and the L2.

At the core of this research lies a detailed exploration of how both language-general factors (e.g., word length and frequency) and task-specific factors (e.g., word order in the experiment) influence eye movement behaviours in reading across linguistically diverse systems. The significant orthographic disparity between Chinese and English provides a unique opportunity to examine how readers adapt their eye movements when navigating typologically distinct scripts, with a particular focus on controlling for common factors such as word frequency and length. Setting the eye movements of these L2 learners against eye movements from L1 reading in English and Chinese offers a broader perspective on reading behaviours across different linguistic backgrounds.

The thesis commences with a thorough literature review, contrasting the dense, spaceless appearance of the Chinese script with the more linear, spaced nature of English writing. This comparison lays the groundwork for a nuanced exploration into how readers modulate their eye movement patterns to accommodate the distinct linguistic structures and challenges presented by each script.

The eye movement investigation is structured around three central research questions. Firstly, it assesses how fixation durations and overall reading patterns vary among Chinese students reading in English, considering the dynamic evolution of these patterns in relation to varying levels of English proficiency and exposure. Secondly, the study investigates the influence of the Chinese script as an L1 on reading behaviours in English as an L2, examining

the potential bidirectional transfer of reading strategies and the impact of prolonged exposure to English on reading behaviours in Chinese. Lastly, the research evaluates the facilitatory vs. inhibitory effects of prior exposure to similar content on reading processes in both L1 and L2, specifically probing how pre-reading similar content in either language under consideration affects subsequent eye movement patterns and reading strategies.

Employing advanced statistical techniques, including Principal Component Analysis (PCA), cluster analysis, and mixed effects modelling, this study provides a comprehensive understanding of the complex interplay between language proficiency, exposure, and cognitive mechanisms in reading across different scripts. The findings of this research significantly contribute to the field of cross-linguistic eye movement research and offer practical implications for language instruction and the development of reading interventions in multilingual contexts.

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Chapter 1: Introduction

1.1 Research Aim

Over the past fifty years eye movement research in reading has investigated "where" and "when" questions (Rayner, 1998, 2009): where do readers fixate their eyes, and for how long do they fixate on each word? Numerous studies have investigated these questions and have studied the associated moment-by-moment cognitive processes during reading. Over the past two decades, a number of formal computational models of eye movement control in reading have been proposed, notably the E-Z Reader model (Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle, Rayner, & Pollatsek, 2003) and the SWIFT model (Engbert, Longtin, & Kliegl, 2002). These quantitative models of skilled reading have been instrumental in accounting for eye-movements during reading in English, contributing to a thorough understanding of monolingual reader behaviour in alphabetic orthographies.

However, because of globalisation more and more people acquire a second language (L2) in addition to their native language (L1). More specifically, as universities welcome increasing numbers of international students, it becomes ever more important to equip these students with advanced reading abilities to help them cope with the demands of their course. To achieve this goal, empirical studies need to be conducted that chart how eye-movements during reading reflect the differences between the L1 and the L2 as well as the influence of the L1 on the L2 and how the eye movements vary based on proficiency in L2 and exposure to L2. The research reported in this dissertation aims to take first steps in this direction by identifying the transfer of eye movement patterns across L1 and L2 through a comparison of the eye-movements during reading of Chinese students who study in the UK and native English speakers.

The questions this thesis aims to answer are:

1. What are the different reading patterns, as indexed by fixation durations and landing position, of Chinese students when reading English as L2 and do these patterns change with English proficiency level and amount of exposure to English?

2. Are the patterns we see in the L2 English reading behaviour of L1 Chinese students influenced by properties of their L1 and the way these L1 properties affect reading? Does extended exposure to L2 alter reading behaviour in the L1?

3. Does prior exposure to similar content facilitate the reading process (as indexed by fixation durations) and eye movement target planning (as indicated by landing position)? Does the language of prior reading of similar content, L1 Chinese or L2 English, play a role in this process?

1.2 Thesis Outline

In Chapter 2, the Literature Review chapter, I provide relevant background of the theories, concepts and models that underpin the studies in this thesis. Chapter 3 provides thorough explanations about the method of the studies in this thesis, including participants, materials, target variables, data preparation, study procedure and participant grouping method. Chapters 4 through 6 focus on three main eye-movement variables in the English reading study. More specifically, each chapter starts with a clear definition of the eye-movement variable, followed by a descriptive analysis for each group and ends with statistical modelling. Chapter 7 presents a summary of the main findings from the English reading study. Chapters 8 through 10 present the main findings from the Chinese reading study which focuses on the same eye-movement variables as the English reading study. Chapter 11 provides a summary of the main findings in the Chinese reading study. As the 'when' aspect of cognitive processing in eye movement research during reading is brought to light, Chapter 12 introduces the 'where' component of oculomotor control in reading. This is done to provide a more comprehensive description of the patterns of eye movements when reading texts in both Chinese and English. Therefore, Chapter 12 undertakes an examination and comparison across both languages, focusing on target planning as the two writing systems exhibit significant differences, including variations in word length distributions linked to the presence versus absence of spacing. Chapter 13 provides a general discussion and conclusion that summarises the findings of the Chinese reading study and the English reading study in terms of the distinct eye-movement patterns between languages.

Chapter 2: Literature Review

2.1 Introduction

Reading is a highly intricate and complicated activity that 86% of language users perform routinely (World Bank, 2023). It encompasses various interconnected elements, including visual perception, attentional focus, and language processing. When individuals engage with written words, they can regulate their reading pace, as initially proposed by Just and Carpenter (1980). This means that readers have the flexibility to adjust their reading speed, skip sections of text, revisit certain parts, or pause at specific words according to their own preferences, thus creating personalised reading 'rhythms'. The comprehension of the text greatly depends on the individual's control over the reading process, as emphasised by Block (1992). In essence, readers' understanding, and assimilation of written material are significantly shaped by their ability to self-regulate and tailor the reading experience to suit their unique needs and to achieve reading fluency.

There is a long history of research on eye movements in reading. The first period of studies of eye movements during reading extended from 1870 to about 1920 (Huey, 1908; Płużyczka, 2018) when some findings about eye movements during reading were revealed and discussed. Huey is considered the creator of the first eye tracker by using a contact lens with an opening for the iris. The lens connected with an aluminium indicator which showed the eye movement. In the same period, E.B. Delabarre created a method of using a cap made of gypsum which adhered to the moist surface of the eye, and using a wire attaching to the cap that led to a lever which drew horizontal movements of the eye on the sooted surface of a cinematographic cylinder. However, these initial eye-tracker equipment were all invasive to the eye which caused significant discomfort to participants. The first non-invasive and precise eye tracker was created in 1901 by Americans R. Dodges and T.S. Cline who had started the development of optical eye trackers; this ensured a breakthrough in the progress of eye tracking technology by using the reflection of light from the cornea. It was in 1905 when the eye tracker could record both horizontal and vertical eye movements thanks to the contribution of Ch. H. Judd, C.N. McAlister and W.M. Steel. The findings in this period mainly pertain to issues about perceptual span (how many letters the eye can effectively see), saccade latency (the time that is needed to initiate an eye movement), and saccadic suppression (no information is perceived during an eye movement).

In the second period from 1920s to 1950s, research focused on eye movements had a more applied focus (Tinker, 1946). Noteworthy discoveries during this era encompass the following milestones. In 1930, Miles Tinker and his colleague conducted an examination into the influence of font type, font size, page layout, and their impact on reading speed and eye movement patterns, employing photographic techniques. Subsequently, G.T. Buswell developed the initial non-contact device for recording eye movements to investigate reading and visual image perception. In 1947, P.M. Fitts and his associates began utilising a film camera to conduct experiments in eye tracking. The 1960s marked the inception of the first eye tracking device resembling modern eye trackers, originally created for the U.S. Air Force and known as the 'oculometer.'

The third period of eye movement research started in the mid-1970s. With the emergence of eye movement recording systems, technological advances facilitated the use of laboratory computers with eye-tracking systems to collect empirical data of eye movements and analyse them. More details can be found in K. Rayner's paper 'Eye Movements in Reading and Information Processing: 20 Years of Research' which presents a comprehensive summary of eye movement studies in reading. It highlights key findings of over two decades of research and underscores the importance of eye-tracking research in understanding reading behaviour and improving reading comprehension.

The fourth period, which started in the late 90s, is characterised by the emergence of elaborated computational (formal) models of eye movements during reading. Those models have been developed to elucidate the role of cognitive processes in reading and to explain basic findings of eye movements during reading.

Before delving into the key findings of the present study on eye movements during reading, it is valuable to revisit noteworthy discoveries from previous research in this area.

2.2 Basic Characteristics of Eye Movements in Reading

This section will recap some significant findings pertaining to eye movements in reading which are closely relevant to the research questions asked in this thesis. The following aspects will be covered, (1) saccades (2) fixations (3) visual acuity (4) perceptual span (5) parafoveal preview effects (Just & Carpenter, 1980; Kliegl et al., 2006; Liversedge & Findlay, 2000; Rayner, 1998, 2009a).

2.2.1 Saccades

Among all the eye movements (i.e., pausing on a word, jumping from one place to another) people make when they are reading, central to this process are the movements of readers' eyes. Saccades are fast, jerk-like rotations of our eyeballs to change the gazing point to select the next point for foveal processing (König, 2010). We constantly make eye movements to search for new information; these jumps are called saccades. In reading alphabetic languages (such as English), readers can use the space between words as a visual cue to help them recognise or isolate individual words. The mean saccade length is about eight letters when reading English silently. When we are moving our eyes during the saccade, a phenomenon named saccadic suppression (i.e., the decrease of the sensitivity to visual input) can be observed. New visual information is gained only during fixation in that vision is suppressed during saccades. Since our eyes move too quickly when we are reading written text, it is unlikely that we acquire new visual information while making saccades (Uttal & Smith, 1968). However, the process of information processing is still working even when readers are making saccades.

In reading, around 10 % of the total reading time, readers move their eyes back to what they have already read. This backward movement is called a *regression*. Many regressions are short, going back a few letters, in the same word or to the preceding word. However, some regressions are long, and may regress to a word on the previous line(s) in a text.

2.2.2 Fixations

The periods between saccades during which the eye is relatively still are referred to as fixations (Reingold & Stampe, 2004). Our eyes remain still when we fixate on one point, and it is found that the duration of a fixation during reading is about 200ms to 300ms. During each fixation, the information (such as the orthographic, phonological, syntactic, or semantic meanings) of the currently fixated word is obtained. New information uptake is largely restricted to these fixations.

Fixation times differ in duration. In alphabetic languages, it is known that word frequency exerts an influence on the fixation time on that word. Many studies provide solid evidence to prove the influence of the frequency of the current fixated word on the length of time spent on the word (Ashby et al., 2005; Inhoff & Rayner, 1986; Rayner et al., 2006), with shorter fixations on high-frequency than on low-frequency target words (Inhoff & Rayner, 1986). Thus, the frequency of the currently fixated word influences the fixation time and leads to the different lengths of fixation times.

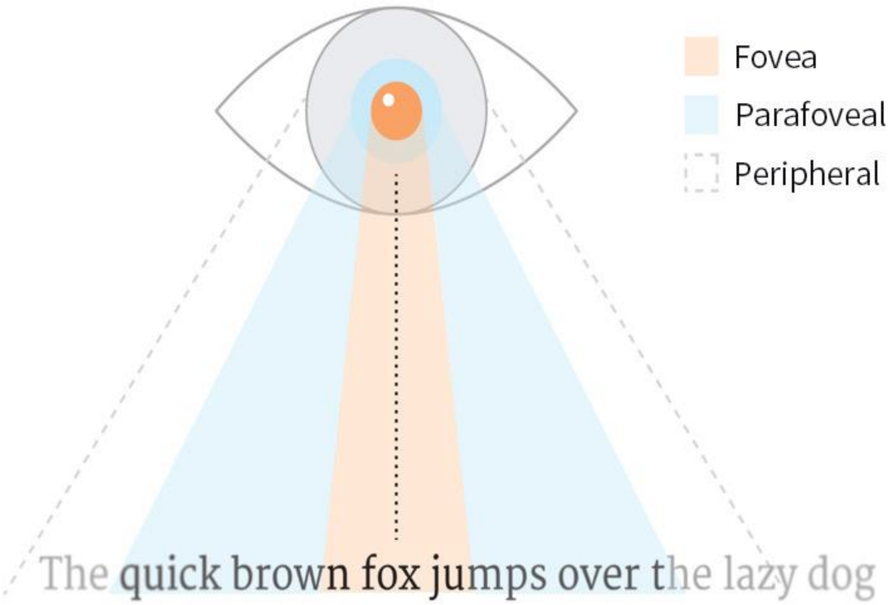
Fixations also differ in place. Given that readers do not have a fixed place on a word to fixate on, their first fixation on a word tends to fall half-way from the start to the middle position of a word (Rayner et al., 1998). Rayner originally labelled this location as the ‘preferred viewing location’ (PVL) (Rayner, 1979). However, in English reading, the target of the initial saccade into a word is generally assumed to be the centre of the word, which constitutes the optimal viewing position (OVP) (O'REGAN, 1987). The OVP is the location in a word where the word can be recognised in the shortest time. The OVP is slightly to the right of the PVL, closer to the centre of the word. The PVL and OVP findings are prevalent in reading alphabetic languages that separate words with spaces.

2.2.3 Visual Acuity

When engaged in reading, there are three distinct areas within the reader's field of view. The initial area is known as the foveal region, positioned at the central 2 degrees of vision. The second region is the parafoveal region, extending approximately 5 degrees on both sides of fixation, just beyond the foveal region. Beyond the parafoveal region lies the peripheral region.

Figure 1

A diagram showing foveal, parafoveal and peripheral regions in reading



Note that the dotted line in the diagram[1] in the middle represents the location of fixation. Acuity is very high in the fovea but will gradually decrease from foveal to parafoveal and peripheral regions. Therefore, to have clear input, readers move their eyes constantly to focus the fovea on the reading materials that they want to see more clearly. However, reading is not just about identification of the fixated word. Instead, fluent reading requires the coordination of the currently fixated word, the previous and overall context and information gained parafoveally. All this information guides the eye movements, i.e. when and where to move the eyes (Schotter, 2018).

[1] Diagram based on Parafoveal processing in reading, https://link. springer.com/article/10.3758/s13414–011–0219–2.

2.2.4 Perceptual Span

Both the information gained from the currently fixated words and from the words in the parafoveal region are involved in the reading process. The span of visual processing is narrow when the readers fixate on the current word. For readers of alphabetical languages such as English with left to right directionality of orthographies, the visual span ranges from no more than 3-4 letters to the left of the beginning of the currently fixated word N to about 14-15 letter spaces to the right of word N (Rayner, 1975).

Rayner (1986) did a study to compare eye movements and the perceptual span of readers with different levels of reading skills. He recruited schoolchildren aged 7-9 years old in Massachusetts, the USA. 6 adults subjects participated in this experiment as skilled readers. He found that the perceptual span in beginning readers is about 11 letters to the right of the currently fixated word, and thus smaller than the perceptual span of readers with higher reading skills, who span 14-15 letter spaces. However, the perceptual spans of both groups are asymmetric to the right side of fixation (Rayner, 1986).

Readers of alphabetic languages can extract various kinds of information from the perceptual span. It has been shown that both orthographic and phonological processing of a word can begin before the word has been fixated (Rayner, 1998). Parafoveal information can trigger word skipping since the word N+1 has already been identified parafoveally when the eyes are still fixated on the word N (Wotschack & Kliegl, 2013). Words with higher contextual predictability have a higher chance of being skipped than words with lower predictability (O’Regan, 1980). Readers can acquire part of the information about the next word (i.e., N+1) to the right of the fixated word N, which may facilitate the lexical access process, to integrate information during a fixation. Furthermore, information about the length of the word N+1 can also be gleaned parafoveally and used in programming a saccade. All this useful information, gleaned from previewing the word to the right of the fixated word N, influences where to move the eyes next, including the saccade length to be made into the next word (Engbert et al., 2002; Engbert et al., 2005; Richter et al., 2006).

To investigate parafoveal processing, most research has made use of the 'boundary paradigm' that Rayner (1975) introduced, in which the parafoveal input is directly manipulated. To do so, an invisible boundary is placed before the target whose parafoveal processing is investigated. As long as the participant's gaze has not crossed this boundary, the target either a) remains the same, b) is masked or c) replaced by a different word. Once the invisible boundary is crossed, the target is displayed in all conditions (i.e., the word is not masked or replaced anymore). The most important finding from this research is the 'preview benefit', which describes the decrease in time that readers spend fixating on the target if they previously received a valid preview as compared to the other two manipulations. For English and other alphabetic languages, the preview benefit appears restricted to the immediately following word and generally no effect is observed if manipulation is administered to the word N+2.

2.2.5 Eye-Movement Measures

In summary, the data collected with a contemporary eye-tracking device can generally be categorised into broader assessments of cognitive workload spanning an entire sentence or text passage, and more detailed evaluations of cognitive workload associated with individual words within a sentence or text passage.

Table 1

Main global measures of reading performance

Measure name	**Values**
average reading rate	250–300 words/min
average saccade length	7–9 characters in length
average fixation duration	200–250 ms
percent regressive saccades	10–15 % of all saccades

Measures of global reading performance encompass metrics such as the average reading rate, average fixation duration, the percentage of regressive saccades, and the total reading time applied across an entire sentence or passage of text. These measures are influenced by factors such as text complexity, the reader's proficiency, and the reader's specific reading goals (e.g., comprehensive reading for understanding versus quick keyword scanning). In particular, increased text complexity, reduced reading ability, and more thorough reading generally result in slower reading rates, shorter saccade lengths, longer fixation durations, a higher frequency of regressions, and extended total reading times.

Local measures of reading performance can be divided into those reflecting early-stage lexical processing (i.e., the earliest phases of lexical access) and those reflecting late-stage, post-lexical processing (i.e., semantic integration and revision). Here we list main measures of reading performance according to Conklin et al. (2018).

Table 2

Definitions of the main measures of reading performance

Early-stage measures	first fixation duration	duration of the very first fixation on a word
	single fixation duration	duration of the only fixation made on a word
	gaze duration	sum of all fixations made on a word on the first pass
	skipping	probability of fixating a word on the first pass
Late-stage measures	go-past time	the sum of all fixation durations on a word starting from the first fixation duration until a rightward saccade is made past the word
	percent regressions	backward saccades
	total reading time	sum of all fixation durations on a word

2.3 Models of Eye Movement Control in Reading

In this section, we will discuss the advances made during the last two decades. This period is characterised by the emergence of elaborated computational (formal) models of eye movements during reading. The computational models can explain the role of cognitive processes in eye movement control in reading and account for some basic properties of eye movements during reading. In the current study, we will borrow some theoretical assumptions of these models to be the mediating variables in examining possible relationships between reading ability and various eye movement measures of reading fluency (e.g., fixation durations).

2.3.1 The E-Z Reader Model

All computational models assume that eye movements during reading reflect ongoing cognitive processes. A popular and representative example is the E-Z Reader, which models skilled reading as a function of cognitive factors, in particular those pertaining to lexical access (Reichle et al., 1998a). To be more precise, one should speak of a family of E-Z Reader models from the last two decades (Mancheva et al., 2015; McGowan & Reichle, 2018; Pollatsek et al., 2006; Reichle & Drieghe, 2015; Reichle et al., 1998a; Reichle et al., 2003; Reichle et al., 2009), which together form a framework aimed at a holistic explanation of eye-movement patterns based on not just lexical access, but also other factors like oculomotor control and attention.

The E-Z Reader is fundamentally serial. Although a word's letters are processed in parallel, a sequence of words is processed one-by-one. The model also assumes that there is a delay between attention shifting and the resulting eye-movement, so that a word parafoveally processed will only be fixated after a lag.

According to the E-Z Reader model, the primary "engine" for eye movements is the lexical processing of every individual word and a saccade is normally targeted at the middle of a word. There are five processes in this model. The first process is a check of how familiar the word is, which means checking whether the reader knows the currently fixated word N for a few milliseconds. The second process is the completion of lexical access of the word. The third process is a "labile stage" of saccade programming that can be cancelled by a subsequent saccade. The fourth process is a subsequent non-labile stage of saccade programming that cannot be cancelled by a subsequent program and the fifth is the actual saccadic eye movement to the next word (word N+1). This decision about where to move the eyes is modulated by low-level information, including the length of the next word and the locations of boundaries between words. In some cases, the word N+1 could be skipped.

The decisions about where and when to jump next are influenced by different factors in the E-Z Reader. The landing position depends mostly on simple bottom-up aspects of the input, in particular the length of the words and spaces between them. The spaces marking word boundaries form an excellent visual cue and it is generally assumed that spaces are the most important factor in determining where to jump next. But the length of the current fixation target as well as that of the following word have also been shown to influence the length of the saccade (Rayner, 1979; Rayner & Morris, 1992), so they are modelled as well.

The timing of the saccades, on the other hand, is based on more high-level, global properties of the input, namely constraints posed by the preceding sentence material and the frequency of the words. It is a well-known finding that the frequency of a word is inversely proportional to its average fixation duration (Inhoff & Rayner, 1986; Just & Carpenter, 1980).

2.3.2 The SWIFT Model

The second key model is the Saccade-generation With Inhibition by Foveal Target (SWIFT) model. This model proposes a control mechanism for fixations, refixation, regressions and landing positions. It has five assumptions, which are '1) spatially distributed processing of an activation field, 2) separate pathways for saccade timing and target selection, 3) random saccade generation within inhibition by foveal targets, 4) two-stage saccade programming and 5) systematic and random errors in saccade length.' (Engbert et al., 2002; Engbert et al., 2005).

Four of SWIFT's main principles are particularly relevant to us. Spatially distributed processing of an activation field postulates that all words compete, and then the following saccades are generated. Spatially distributed processing of the activation field during eye movements allows for the integration of information from multiple spatial locations. Peripheral vision plays a crucial role in scene perception, object recognition, and contextual processing, complementing the high-resolution processing of the fovea. By distributing attentional resources across the visual field, the visual system can gather information from different spatial locations and maintain awareness of the overall visual scene.

Secondly, if there are separate pathways for saccade timing and saccade target selection, the target location of the saccade is generated by a process that is separate from the one which determines the moment in time when the saccade is launched, and these processes are sensitive to different factors.

The third principle is the autonomous saccade generation with time-delayed foveal inhibition. Saccade programs are generated autonomously, so that fixation durations are basically realisations of a random variable.

The fourth principle is the two-stage saccade programming with labile and nonlabile levels, which is similar to the E-Z Reader (for a comprehensive and detailed review (Engbert et al., 2002; Engbert et al., 2005; Richter et al., 2006)). A saccade is programmed in two stages. First comes the labile stage, where the oculomotor apparatus is prepared for the upcoming saccade. This level is called labile, because it can be cancelled through the initiation of a new saccade. When the preparation stage is completed, the location of the saccade is determined, and the saccade is launched. This stage is called the nonlabile level because the saccade cannot be cancelled anymore (Engbert et al., 2002; Engbert et al., 2005; Richter et al., 2006).

2.3.3 Differences Between the Two Models

There are differences between these two models. Firstly, Serial versus Parallel Processing: E-Z Reader is primarily a serial processing model, whereas SWIFT incorporates parallel processing. E-Z Reader posits that word processing occurs sequentially, one word at a time, with fixations and saccades organised serially. In contrast, SWIFT incorporates parallel processing, suggesting that multiple words can be processed simultaneously, with interactions and influences between neighbouring words (Reichle, 2006).

The second difference is related to saccade generation mechanisms. E-Z Reader proposes a direct control approach, where saccades are planned based on word processing times and lexical properties. It emphasises the influence of visual and linguistic factors on saccade programming. SWIFT, on the other hand, incorporates inhibitory signals and the timing of foveal inhibition to determine the next saccade target. It focuses on the interplay between inhibitory processes and lexical factors in guiding saccade generation.

The third difference lies in processing dynamics. E-Z Reader places significant emphasis on word frequency and the timing of lexical processing. It predicts that word frequency affects the duration of fixation, with high-frequency words processed more quickly. SWIFT considers a wider range of factors, including word length, visual constraints, and contextual predictions, in addition to word frequency. It highlights the interplay between multiple factors in determining saccade programming and fixation durations.

The fourth difference pertains to the role of Parafoveal Information. E-Z Reader incorporates limited parafoveal processing, primarily using it to facilitate word identification. It suggests that parafoveal information is not crucial for saccade programming. In contrast, SWIFT highlights the importance of parafoveal preview and the use of contextual cues in guiding saccades. It proposes that parafoveal information can influence saccade programming and contribute to efficient eye movements.

Another distinction pertains to how cognitive and lexical characteristics of the word being fixated affect the duration of time readers allocate to processing that specific word. According to the E-Z Reader model, lexical processing serves as the driving force guiding the progression of the eyes through the text. In contrast, the SWIFT model suggests that saccades are spontaneously generated with intermittent cognitive impact. This implies that challenges in lexical processing can impede the initiation of saccades.

2.3.4 Distinct Predictions

The E-Z Reader model and SWIFT model offer distinct predictions regarding various aspects of eye movements. Here are some key differences in their predictions:

1. *Fixation Duration*: E-Z Reader predicts that fixation durations are primarily influenced by low-level visual properties, such as word length and visual complexity. It places less emphasis on higher-level linguistic and contextual factors. In contrast, SWIFT predicts that fixation durations are influenced by a broader range of factors, including lexical and contextual information, word frequency, and parafoveal pre-

processing. SWIFT suggests that fixation durations can be modulated by both low-level visual cues and higher-level linguistic processing.

2. *Parafoveal Preview Benefit*: E-Z Reader predicts that the preview benefit arises from the early pre-processing and identification of upcoming words in the parafoveal region. It emphasises the role of visual and low-level cues in facilitating word recognition and reducing fixation durations for previewed words. SWIFT also acknowledges the parafoveal preview benefit but provides a more detailed account. It emphasises the integration of lexical and contextual information, attentional guidance, and inhibitory processes in predicting the magnitude of the preview benefit.

3. *Parafoveal-on-Foveal (POF) Effect*: E-Z Reader predicts a significant POF effect based on the early activation and priming of the fixated word due to parafoveal pre-processing. It suggests that the processing of the fixated word benefits from the preactivated representation of the parafoveal word. SWIFT also predicts a POF effect but places more emphasis on attentional guidance and inhibitory mechanisms. It suggests that the parafoveal information guides attention and influences the allocation of processing resources to the fixated word while inhibitory processes attenuate interference from the parafoveal word.

4. *Influence of Lexical Factors*: E-Z Reader places significant emphasis on the influence of lexical properties, such as word frequency and predictability, on eye movements. It predicts that these factors affect various aspects of eye movement, including fixation durations and saccade programming. SWIFT also considers lexical factors but incorporates them within a broader framework of attentional control, inhibition, and contextual influences.

In summary, E-Z Reader and SWIFT differ in their predictions regarding fixation durations, parafoveal processing effects, and the influence of lexical and contextual factors on eye movements during reading. While E-Z Reader emphasises low-level visual cues and early word identification, SWIFT provides a more comprehensive account by incorporating attentional guidance, inhibitory mechanisms, and a wider range of linguistic and contextual influences. Understanding these differences enhances our understanding of the complex interplay between visual, linguistic, and cognitive factors in eye movement control during reading.

2.3.5 Interim Conclusions

Although these two models were designed to account for empirical eye-tracking data, initially, they both dealt mostly with the reading of alphabetic languages; hence, their principles and assumptions are mainly derived from work on alphabetic languages. If we want to test the general applicability of current models of eye movement control in reading, it is necessary to test how effectively they can be used to account for eye-tracking data from reading a non-alphabetic language. Chinese, which is typologically unrelated to English, offers the opportunity to test the generality of the accounts offered by computational models of eye movement control in reading, for example, E-Z Reader has been extended to account for the eye movements of Chinese readers with reasonable success (Rayner, Li, et al., 2007). However, more studies are needed in this respect to establish whether the control of eye movement during reading in a language like Chinese is fundamentally different from reading in English.

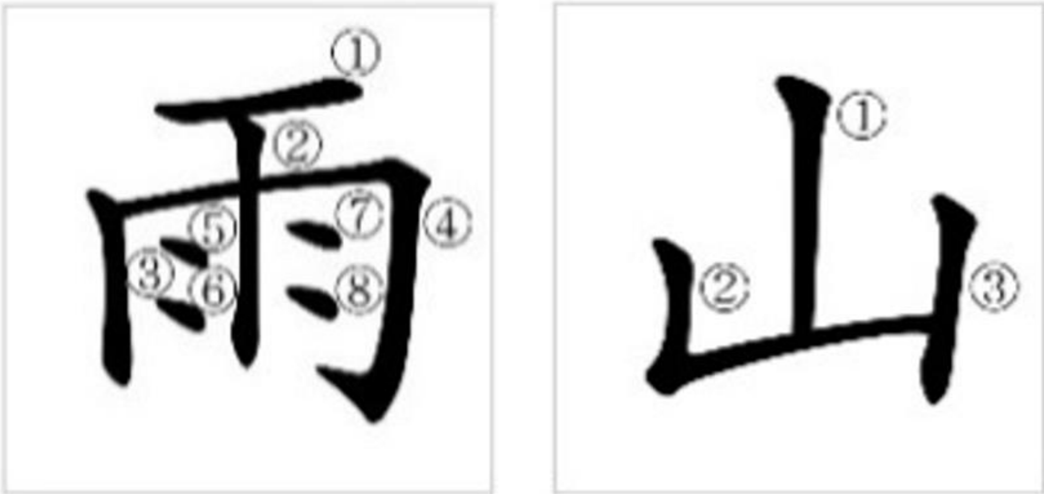
2.4 Chinese and English - Two Typologically Unrelated Languages

In this section, we will systematically review some facts about the linguistic differences between Chinese and English. We will focus on the differences that are related to the specific eye movements that the character-based writing system of Chinese requires from its readers.

2.4.1 From Strokes Over Characters to Words

Unlike the Indo-European languages, written Chinese is ideographic. There are many visual details contained in a Chinese character and Chinese characters differ much visually. Strokes are the smallest building materials of Chinese characters, which are composed of between 1 to over 20 strokes (Li et al., 2014). There are about 20 basic strokes in Chinese, among which, 一丨丿㇏㇈乙乚亅丶㇆. For example, three strokes 丨(O),乚(O),and 丨(O) constitute the character 山(shan1[2], mountain); eight strokes 一(O)丨(O)㇆(O)丨(O)丶(O)丶(O)丶(O)丶(O) constitute the character 雨（yu3, rain）.

[2] Chinese *pinyin* is the official romanisation system for Chinese in mainland China. The system includes four diacritics denoting tones.



One level up from strokes are the radicals, which constitute subparts of characters. In most cases, radicals determine the basic semantic meaning or the pronunciation of characters. For example, the radical 口 represents mouth-related meanings: 叫 means shouting, 吠 means barking, 叹 means signing. The radical 氵 represents water-related meaning (泳 means swimming, 江 means river).

There are two types of Chinese characters: single and composed (the latter making up over 90% of all Chinese characters). Single characters cannot be divided into smaller parts, such as 月（yue4）means moon, 火（huo3）means fire. As their name indicates, composed characters can be divided into different subparts. For example, the composed character 读（du2）which means reading has 10 strokes, but only 2 radicals (讠 and 卖); the composed character 热（re4）which means hot has 13 strokes, but only 2 radicals (执 and 灬). Some radicals can also be used as a character on their own, with their own pronunciation and meaning (s); the radical 广 (guang3), has the meaning of ‘wide’. Yet, in the composed character 床（chuang2）which means ‘bed’, 广 is just one radical of the character.

Characters can be composed in different ways. The two most common structures of composed characters are left-right and up-down. For example, 笋 (sun3, ‘bamboo shoot’) has a top-bottom or vertical structure radicals, ⺮ and 尹, and 忘 (wang4, ‘forget’) is composed of 亡 and 心.

The closest English equivalents of Chinese characters are morphemes, the smallest meaning-bearing units. About 60–70% of words in Chinese consist of 2 characters; one-character words make up about 5–10%, about 10-15% of words have 3 characters, and 5-10% of words contain 4 characters. Only a limited number of Chinese words have more than 4 characters (Wang et al., 2003).

An eye-catching difference between alphabetic scripts such as English and a logographic system such as Chinese is the space between words. In Chinese, there is no space between continuous strings of characters serving as unambiguous visual cues to word boundaries. Several recent investigations have explored the potential benefits of inserting spaces between words in Chinese text for readers (Bai et al., 2008; Inhoff & Liu, 1997; Zang et al., 2013). Among native Chinese speakers, including both adults and children, no statistically significant disparities were observed in sentence reading durations when comparing traditional unspaced text with spaced text. Bai and colleagues asserted that any advantages derived from offering readers explicit and unambiguous word boundaries were offset by the atypical visual presentation of spaced text to native Chinese speakers. Although English natives can accurately segment words when reading even without spaces, studies have shown that in that situation, readers' reading efficiency does drop (Rayner, Fischer, & Pollatsek, 1998b; Rayner & Pollatsek, 1996).

2.4.2 Interim Conclusions

This section has briefly listed the differences between the Chinese character-based writing system and the writing system used in alphabetic languages (English in particular). All these differences between Chinese and English undoubtedly triggered researchers' interest in exploring the various eye movements characteristics in reading Chinese and English. How are words segmented in Chinese during reading (Li et al., 2009)? Without visual boundaries between words, how do Chinese readers determine where to send their eyes (Li et al., 2011)? How do the properties of words modulate eye movements during reading Chinese? How do the processes of reading Chinese and English differ pertaining to eye movements? Those questions have led researchers to examine eye movements while reading Chinese, and these studies will be reviewed in the next section according to different perspectives.

2.5 Eye Movements in Reading Chinese

Over the past decade, there has been a steep increase in eye movement research investigating reading Chinese. The studies focus on whether the word or character is the basic information unit (Bai et al., 2008; Li et al., 2014; Yan et al., 2006; Yu et al., 2018). Other well-debated topics about reading Chinese are landing position (Zang et al., 2013), preview benefit (Bai et al., 2015; Tsai et al., 2012; Ming Yan et al., 2012; Yang et al., 2012), and saccade programming (Liu et al., 2015; Wei et al., 2013; Yan & Kliegl, 2016; Yan, Kliegl, Richter, et al., 2010), to name but a few. In this section, we will review these well-debated topics in turn, i.e., the effect of adding spaces as visual cues in reading Chinese, the basic processing unit in reading Chinese, the perceptual span in reading Chinese, preview benefit effects in reading Chinese and landing position.

2.5.1 The Role of Spaces

Chinese differs from English and many other alphabetic languages in that it does not have physical boundaries between its basic information units. In English, it is easy for readers to segment words with the help of spaces. Quite a few researchers have tried to investigate the role of spaces in the reading process and how the no-space factor influences eye movements in reading Chinese.

The spaces in alphabetic writing systems are beneficial to the reader in that they identify each word's position as well as its length, which the reader can use to plan fixations (Wei et al., 2013). Without the word boundaries, saccade lengths decreased, while fixation times increased inversely proportional to word-frequency (Rayner et al., 1998). The authors highlighted two obvious potential negative consequences of the lack of spaces. Firstly, the removal of space information hinders the process of computing saccadic programming. Secondly, loss of space information potentially makes it harder for readers to find the first and last letters of words and to determine where the words end and begin, influencing the process of word identification.

Given this, will adding spaces as visual cues during reading to writing systems without clear visual boundaries facilitate readers' eye-movement programming? With this question in mind, researchers shifted their attention to writing systems that do not include spaces between words. For Thai, researchers found decreased reading times for passages after they added spaces between words (Kohsom & Gobet, 1997). A similar finding was reported for Japanese (Kajii et al., 2001). In this experiment, the mean gaze duration per word as well as the total time spent reading sentences were measured, which were both reduced through the addition of spaces.

However, there is currently no evidence that reading Chinese benefits from adding spaces between words. Bai et al. (2008) used four types of spacing in their experiment: normal unspaced text, spaces between words, spaces between characters that do not constitute words, and spaces between every character. Their results indicated that inserting spaces between words did not help Chinese reading (Bai et al., 2008). Non-word spacing (putting spaces in the wrong place) and a space between every individual character led to longer reading times. Their conclusions are two-fold: 1) a more familiar visual text format which is characters with no space should produce shorter reading times than a new format, in this case the spaced one 2) when space is inserted between every character, the resulting text will inevitably be longer than without spaces, which makes single character spacing disruptive to processing.

The same negative effect of adding spaces/visual cues in written languages can also be witnessed in Finnish. Finnish has simple a syllable structure, and syllables are basic processing units in word recognition. Syllabification is highly emphasised in Finnish reading. To help Finnish children who are early readers to read Finnish words, hyphenation of multi-syllable words is used in Finnish textbooks in year one and year 2 in elementary school. Yet, the hyphenation of multi-syllable word is removed starting from year 3 in elementary school. However, recent evidence proves that this hyphenation does not help the process of word recognition. Hyphenation was beneficial for the less proficient reader, but second graders who were higher proficient readers read concatenated compounds faster than hyphenated compounds (Häikiö et al., 2016). This is because the hyphens attract readers initial attention to the first morpheme of the word, which triggers the morphemes to be processed one by one rather than as a holistic unit. This sequential morpheme-based presentation causes disruption to proficient second graders. As reading skills develop, words are more likely to be recognised through orthographic units in Finnish (Häikiö et al., 2018; Häikiö et al., 2015).

As both the results of adding spaces in Chinese and hyphenation in Finnish reading indicate, adding physical cues may only have limited impact. This might indicate that skilled readers of Chinese do not use spatial cues to guide their eyes. What physical factors, then, might guide Chinese readers' eye movements, given the lack of spaces as visual cues to facilitate eye-movement programming to reach reading fluency?

2.5.2 Basic Processing Unit in Reading Chinese

Among previous studies on European languages a large number have taken the word as a basic processing unit. In their effort to extend the E-Z Reader model (which will be explained in Section 5) of eye movement control to Chinese readers, Rayner, Juhasz, et al. (2007) paid attention to the word/character issues. They treated the word as an orthographic unit, the same with English and they used words as the basic processing units (Rayner, Li, et al., 2007).

Aside from how adding spaces between morphemes or words changes reading patterns, for Chinese it is even controversial how to unite characters into words (Li et al., 2009). However, to investigate the cognitive mechanisms underlying reading, it is necessary to know what the basic processing unit is that they operate over. On the one hand, there is the national standard CCLWSSIP (Chinese Language Word

Segmentation Specification for Information Processing), which specifies how words should be segmented in Chinese. On the other hand, a study of 142 Chinese university students found that this standard was not entirely followed when the students had to segment sentences and that their segmentations were dependent on the syntactic context. To a Chinese reader, then, a word might be something very different from what it is to a linguist and what it is to another Chinese reader.

If that is the case, words might not be the most relevant unit for Chinese reading. This is what has been argued by Chen and Liu (2000) who instead propose that characters are more salient units, an opinion shared by other researchers (Li et al., 2014). A character may be a free morpheme, for example, 光 (guang1) means light. However, the word 时光 (shi2guang1) means time, and wrong segmentation at the character-level may lead to different word meanings.

This stance is challenged by findings of strong effects in reading Chinese that are based on the word as a unit. Words that are highly frequent or highly predictable, for example, are read with shorter time and with more skipping than words of low frequency and these effects are stronger than those for measures based on letters (Li et al., 2009; Rayner et al., 2005; Yan et al., 2006). The study by Bai et al. (2008), which we discussed earlier, also supports this, as breaking up words by adding spaces was disruptive to readers. Furthermore, the word superiority effect, which is the finding that a letter is recognised faster if it is part of a word as opposed to be part of a pseudo-random string of letters, also holds for Chinese (Li et al., 2009).

2.5.3 Perceptual Span in Reading Chinese

In Chinese reading, the perceptual span is narrow, extending at most up to one character to the left and two to three characters (roughly two words) to the right of fixation (Inhoff & Liu, 1997). The perceptual span extends 3-4 letters to the left and 14-15 letters to the right of fixation in reading of alphabetic langauges (Rayner, 1975).

Keung and Hoosain (1989) notes that the Chinese writing system interacts differently with properties of the visual system than alphabetic languages like English do. The high information density that a Chinese reader is presented with foveally, balanced by the lack of parafoveal information, presents a trade-off that alphabetic languages strike differently (Keung & Hoosain, 1989).

Zhu et al. (2019) did a study on the perceptual span of Chinese second year high school students. The subjects were 16 Chinese year 2 high school students with average age of 17.5. The first finding is that with their specific reading materials, subjects' reading perceptual span ranges from 1-2-character spaces to the left of fixation and 3-4 characters to the right of fixation. Secondly, the saccade length is about the length of three Chinese characters, and the perceptual spans of successive fixations slightly overlapped. Inhoff and Liu (1998) employed eye-movement-contingent display adjustments to manage the visibility of characters while participants read Chinese text. Furthermore, their findings revealed that Chinese readers exhibit an asymmetric perceptual span, spanning one character to the left of the current fixation character and three characters to its right. Additionally, the size of right-directed saccades encompassed spaces equivalent to 2-to-2.5 characters, suggesting the integration of linguistic information across fixations, as the perceptual spans of consecutive fixations partially overlapped.

2.5.4 Preview Benefit in Reading Chinese

As discussed in the previous section, readers of Chinese also have an asymmetric perceptual span. In principle, when reading Chinese, if the word N+1 is short enough, even the word N+2 may be within the perceptual span (Ming Yan et al., 2012). Many scholars who are interested in eye-movement research are particularly interested in semantic parafoveal processing in reading Chinese. There are several reasons for this. The most important one is that Chinese orthography encodes meaning rather than pronunciation (Yan et al., 2009). Furthermore, the lack of word boundaries and the fact that words longer than three characters are rare in Chinese means that the upcoming character is more likely to be part of the perceptual span than in alphabetic languages.

Yen and colleagues suggest that parafoveal uptake happens early during a fixation, and is used to find the boundary of the word being fixated (Yen et al., 2009). They found preview benefits for Chinese that are comparable to those in English, as participants reading sentences spent less time on the pre-target if they were presented with a preview at the beginning or the end of the fixation of the currently fixated word. Looking for semantic effects of parafoveally presented words in non-compounds, Yan and colleagues (2009) report two findings. First, they found a reliable preview benefit for semantic and orthographic properties of the previewed words. Second, the preview benefit related to phonological properties of the previewed words was weaker or later than the semantic benefit or might be non-existent, as it did not reach significance.

M. Yan et al. (2012) also investigated whether Chinese readers experience semantic preview benefits based on lexical and sub-lexical properties (obtained from strikes or radicals) of the parafoveal input (compound characters). Their findings suggest that 1) there is a “pure” semantic preview benefit in Chinese that is independent of the contextual plausibility of the preview and 2) that this benefit can be due to an overlap of sub-lexical (radical) units and not just whole words.

2.5.5 Landing Position in Reading Chinese

As discussed in section 2.2.2, the findings related to preferred viewing location are found most in alphabetic language reading where words are separated by spaces. The spaces between the words in alphabetic languages provide a very clear visual cue to help readers programme their saccades to the next fixation location, i.e., the preferred viewing location. However, only limited research has been conducted to investigate saccadic targeting in unspaced languages. Sainio et al. (2007) reported that the optimal viewing position in Japanese did not show a U-shaped curve where the inner zones are associated with shorter gaze durations than the outer positions. By analysing the initial fixation position, when the spaces were added in Hiragana, the initial landing position in words moved towards the word centre (Sainio et al., 2007). In a study by Winskel et al. (2009) on landing position in Thai an alphabetic language but written without spaces, Thai-English bilinguals read sentences in a 2x2 design (sentences were read in both English and Thai and both with and without spaces). In Thai, an alphabetic language typically written without spaces, sentences were presented in both high-frequency (HF) and low-frequency (LF) contexts. For instance, an HF sentence in Thai, 'พ่อชอบอาหารรสจัด' (pĥx chxb xāh̄ār rsc cạd), which translates to 'My father likes food that is highly seasoned,' was read in both its natural unspaced form and an artificially spaced format as 'พ่อ ชอบ อาหาร รส จัด'. Similarly, an LF Thai sentence, 'พ่อชอบอาหารรสจัดที่มีซอสพริก' (pĥx chxb xāh̄ār rsc cạd thī̀ mī̂ s̄xs̄ prīk), meaning 'My father likes chili sauce that is highly seasoned,' was presented with and without added spaces. These Thai sentences were compared to English sentences under the same conditions to investigate the role of inter-word spacing on eye movement behaviour and reading efficiency. Participants' eye-movements were tracked and compared to those obtained from monolingual English speakers as they read the sentences in English. For the Thai texts, the initial saccade landing positions did not differ significantly in the two spacing conditions. Removing the spaces from the English texts, however, resulted in initial landing positions that were less far into the target word.

Li et al. (2011) tried to establish whether there is a preferred viewing location in reading Chinese. Their findings are threefold. Firstly, Chinese readers' eyes locate about all saccades into the target words near the beginning of the word. Secondly, for readers who only made a single fixation on a word, they tended to land in the centre of a word. However, the third finding is that when readers made more than one fixation on a word, they landed at the beginning of a word. These three results show that the landing positions change dynamically in reading Chinese, depending on whether eye movement target planning for Chinese is treated as character-based or word-based. But the second finding indicates that, even without clear visual cues such as spaces, Chinese readers also tended to land in the centre of words, i.e. at the optimal viewing position in English reading (Li et al., 2011).

Zang et al. (2013) examined the effect of adding spacing between words on landing position while reading Chinese. In this study, researchers considered landing position data in two different cases, i.e., a single fixation case and a multiple fixation case. They found that when there was more than one fixation, the initial fixations were located near the beginning of the word. However, if readers only made a single fixation, they tended to land toward the centre of that word, according to Yan, Kliegl, Shu, et al. (2010). Besides, they proposed that whether Chinese readers land at the beginning or centre of words depends on whether they successfully segment the word boundaries parafoveally.

2.5.6 Interim Conclusions

The preceding section has presented a comprehensive overview of the research findings regarding eye movements in the context of reading Chinese. This section explored multiple aspects, including the role of spaces, the identification of the basic processing unit in reading Chinese, variations in perceptual span, the preview benefit experienced during Chinese reading, and noteworthy discoveries related to the landing position. The primary aim of these studies was to compare the mechanisms of eye movements observed in reading Chinese with those identified in the context of alphabetic languages. By conducting cross-linguistic investigations, researchers sought to uncover the potential influence of different writing systems on eye movement mechanics and understand the interplay between language and reading processes.

It is important to acknowledge that the participants involved in these studies were primarily native speakers of the language being read, thus limiting our understanding of how individuals learning a second language approach reading tasks and how their proficiency level and exposure to the second language influence their control over eye movements. Likewise, despite the wealth of research on L1 eye movements in reading, there is a dearth of knowledge regarding the reading behaviour of language learners in their target language, particularly in relation to their second language (L2) proficiency and exposure.

Previous studies have predominantly focused on examining eye movements from the perspective of first language (L1) speakers, inadvertently neglecting the unique challenges and strategies employed by second language learners. To address this significant research gap, it is imperative to expand the scope of investigation and include language learners as participants in studies exploring eye movements during L1 and L2 reading. By specifically examining the eye-movement patterns and mechanisms utilised by L2 readers, we can gain valuable insights into the distinct cognitive processes involved in L2 reading and elucidate the complex relationship between language acquisition, eye movements, and reading comprehension. Moreover, such expanded research endeavours hold the potential to contribute not only to a more comprehensive understanding of the reading process but also to provide practical guidance for language educators and learners. Therefore, future studies should focus on investigating how second language learners read in their language of study and how their L2 proficiency and exposure influence their control over eye movements when reading L2 texts. These efforts will undoubtedly enrich our knowledge and contribute to the development of effective strategies for L2 reading instruction and assessment. Furthermore, while there is work on first language attrition due to immersion in an L2 contact, there is a lack of research on whether and how extended exposure to an L2, and reading in the L2, affects reading in the L1. Siu and Ho (2015), in their research, investigated bidirectional language transfer by assessing the impact of syntactic skills on reading comprehension in two distinct languages. Their findings indicate that bilingual learners leverage the similarities in syntax between their first language (L1) and second language (L2) to facilitate their L2 learning process. However, it is worth noting that in the existing literature, the influence of L2 on L1 is typically examined within the context of "attrition" or "language loss." While some studies have explored L2 transfer effects, most subsequent language studies have predominantly focused on language transfer from L1 to L2, with limited attention given to the reverse direction. This directionality suggests that earlier linguistic and cognitive habits established in the first language shape or impact the learning and use of a second language. This assumption has been common in areas like language acquisition, bilingualism, and language education.

However, the reverse direction where L2 influences L1 is less explored and could offer valuable insights into the dynamic nature of bilingual or multilingual language competencies. This aspect might include how advanced proficiency in a second language might introduce new syntactic structures, vocabulary, or even idiomatic expressions into the first language. The concept also opens up discussions about the fluidity and evolving nature of language skills in multilingual individuals, challenging the traditional view of language skills as being static once adulthood is reached.

2.6 Reading English as a Second Language

2.6.1 L2 Exposure and Eye Movement Patterns of EFL Learners

Reading is not an innate ability. It is a skill that develops over time through educational progress. When it comes to reading in a second language (L2), this development becomes even more challenging and intricate. L2 learners face complexities, including the interference of their first language in their L2 reading, known as crosslinguistic effects (Koda, 2007). Additionally, L2 learners must meet the specific demands of the L2, such as grammar, syntax, vocabulary, and morphology.

As a result, foreign language learners, who are exposed to the effects of their native language, are required to cultivate their skills in vocabulary, syntax, and morphology in the new language to become proficient readers. Furthermore, the processes of reading in one's native language (L1) and reading in a foreign language (L2) may be entirely distinct. L1 and L2 readers thus embark on their reading journeys from very different starting points.

According to research on L1 reading, children who begin to learn to read in their native language typically already know between 5,000 to 8,000 words before formal education begins (Cunningham, 2005). Moreover, individuals who are beginners in their first language (L1) already have a significant level of morphological, phonological, and syntactic knowledge of their native language. This knowledge is acquired through exposure in their social environment before they receive formal reading instruction.

In contrast, novice L2 learners in a foreign language context start to learn L2 reading without much prior linguistic knowledge of the target language. In other words, they lack the social exposure and the extensive mental lexicon, as well as the fundamental linguistic knowledge of the target language at the time their reading instruction begins. L2 learners typically require several years to establish a robust implicit grasp of vocabulary, morphology, syntax, and phonology, all of which are essential for effective reading comprehension (Grabe, 2010). In this regard, it is valuable to employ eye movement research in reading to uncover insights into how L2 learners progress from novice to proficient readers. This research can also help identify potential influences of L2 exposure, linguistic knowledge, and other relevant factors on the reading development of L2 learners.

Experience (exposure) exerts an important part in the development of reading literacy. Put differently, greater exposure to printed materials influences the skills that are needed in reading, such as competence in phonological decoding, rapid decoding of orthographic information, and morpho-syntactic competence (Cunningham & Stanovich, 1990). Proficient readers extract the orthographic patterns of written words, decipher their phonological representations, and employ these to access lexical and semantic knowledge preserved in their mental lexicon. Through reading experience, readers gain language skills, including orthographic knowledge, phonological processing skills and sentence comprehension skills which are key contributors to reading ability. A considerable amount has been learnt about the mental processing that supports skilled reading using eye movements. There are many hypotheses that lexical processing proficiency mediates reading. Expanding on this, the depth of a reader's lexical knowledge—comprising the recognition and understanding of a vast array of words and their nuances—directly influences reading times. As readers encounter a word, those with a more developed lexical database can process and comprehend the word more quickly, resulting in shorter reading times. This proficiency in accessing and retrieving lexical information streamlines the reading process, making it more efficient and less time-consuming. The relationship between rich lexical knowledge and expedited reading time indicates that readers who have extensively engaged with a variety of texts develop a more understanding of language nuances, which in turn supports faster reading fluency. For instance, Perfetti's lexical quality hypothesis (Perfetti, 2007) suggests that the ability to effectively retrieve orthographic, phonological, and semantic information from print, which hinges on the quality of one's lexical representations, is a fundamental factor in defining reading skills. To answer the question of what allows a beginning reader to become a skilled reader, i.e., reading skill development, Mancheva et al. (2015) conducted a research study employing the E-Z reader model to explore potential connections between the previously mentioned reading proficiency and various eye-movement measures related to reading fluency, such as fixation durations. Their objective was to elucidate the reasons behind the divergent eye movement patterns observed between novice readers and proficient readers, offering valuable insights into the cognitive processes crucial for acquiring reading skills. The study involved the collection of eye-movement data from a group of 15 adults (aged 23–29 years) and 106 children (aged 10–13 years, with a mean age of 11 years). They compared the first fixation duration, single fixation duration, and gaze durations between the adult readers and children. The findings revealed that adults typically have shorter fixation durations compared to children. Furthermore, the study identified that variations in reading abilities are attributable to disparities in lexical processing proficiency, encompassing aspects like orthographic knowledge, phonological processing skills, sentence comprehension, and overall intelligence.

Changes in how readers respond to word frequency with age can serve as an indicator of their orthographic decoding strategies in reading (for example, Kuperman & Van Dyke, 2011). Additionally, the way sensitivity to word frequency develops with increased exposure can reflect the depth of word form integration in memory (as seen in Cop, Keuleers, Drieghe, & Duyck, 2015; Whitford & Titone, 2012). Compared to proficient readers, those with less skill often exhibit longer fixation times, increased refixations and regressions, and spend more time reading text passages (such as in

Spichtig et al., 2017). This indicates that processing linguistic information is more laborious for them, with lexical processing being slower in the early stages of reading and becoming more fluent and automatic as proficiency develops. Similar patterns in the development of L2 lexical processing have been observed, with studies demonstrating quicker word recognition in bilinguals who have more extensive L2 experience (for instance, Diependaele, Lemhöfer, & Brysbaert, 2013; Whitford & Titone, 2012, 2015).

Using eye movement measures of L1 and L2 paragraph reading, Whitford and Titone (2012a) investigated the relations between the relative size of L1 and L2 frequency effects and the degree of current L2 exposure. They collected eye-movement data of 125 bilinguals (75 English-French, 50 French-English) and L1 versus L2 exposure data with a self-reported assessment questionnaire (with 57 participants in the high L2 exposure group and 60 in the low L2 exposure group). The findings indicated that, in comparison to their first language (L1), bilinguals exhibited more pronounced effects of word frequency in their second language (L2) during both early and late phases of eye movement measurements. These phases are believed to correspond to initial and post-lexical access stages, respectively. More specifically, they found that the magnitude of L2 frequency effects was inversely related to current L2 exposure, such that lower levels of L2 exposure led to larger L2 frequency effects. Expanding on their observations about how variations in current L2 exposure among bilinguals influence paragraph-level reading in both L1 and L2, Whitford and Titone (2015) conducted a study to explore the broader impact of L2 exposure on overall reading performance. This included examining global eye movement metrics and how bilinguals process parafoveal information to the right of fixation in sentence-level reading in both L1 and L2, using a gaze-contingent moving window paradigm. Their results indicated that bilinguals with higher versus lower current L2 exposure demonstrated improved L2 reading fluency, as evidenced by quicker reading speeds and shorter forward fixation times, alongside a decrease in L1 reading fluency (characterised by slower reading speeds and longer forward fixation times). Additionally, they observed that those with greater L2 exposure were more affected by smaller window sizes in L2 reading, suggesting a broader L2 perceptual span, but were less impacted in L1 reading, implying a narrower L1 perceptual span. These findings imply that the degree of current L2 exposure in bilinguals can affect broader aspects of reading behaviour, including overall reading difficulty and the distribution of visual attention in the parafovea during sentence reading in both L1 and L2.

Leung et al. (2014) examined the extent of the perceptual span in the context of second language reading. The study involved the measurement of the perceptual span in university students in Japan who were learning English as a foreign language (EFL), with the aim of investigating parafoveal processing during the reading of a second language (L2). Employing the gaze-contingent moving window paradigm, they conducted a comparative analysis of the perceptual span between 42 Japanese EFL readers and 14 native English L1 readers. The study yielded two primary findings. Firstly, the EFL readers exhibited a smaller perceptual span in comparison to the L1 readers. Secondly, the effect of parafoveal information was more pronounced for faster EFL readers in comparison to slower EFL readers. Based on these findings, the researchers concluded that EFL readers have limited capacity to utilise parafoveal information during fixations in comparison to L1 readers.

2.6.2 L2 Proficiency and Eye Movement Patterns of EFL Learners

Eye tracking has long been recognised as a robust method for investigating differences in reading skills. Numerous studies have demonstrated a close relationship between reading proficiency and eye movements. For instance, Rayner (1998) observed that as reading proficiency improves, there is a decrease in fixation duration, regressions, and fixation count, while saccade length increases. According to earlier research, novice readers had an average fixation duration of approximately 355 milliseconds, a fixation count of 191 per 100 words, and a regression rate of nearly 30% (Rayner 1985, McConkie et al. 1991). Conversely, skilled readers exhibited notably lower values in these measures, around 233 milliseconds, 94 fixations, and a regression rate of 14%.

Similarly, a study by Rayner (1978) also yielded consistent results for a group of 10 proficient readers, with an average fixation duration of 216 milliseconds, an average saccade length of 8.1 letters, and a regression rate of 11%. Furthermore, additional eye movement metrics, such as refixations, have been found to correlate with reading proficiency. McConkie et al. (1991) reported that novice readers tend to fixate on words more frequently compared to skilled readers.

The primary objectives of Dolgunsöz and Sarıçoban (2016) were two-fold. Firstly, they aimed to investigate the relationship between foreign language reading proficiency and eye movements during reading. Secondly, they sought to describe the differences in eye movement patterns between two CEFR proficiency groups, specifically those classified as B1 and B2. The researchers employed the use of eye tracking technology and conducted experiments involving 57 learners of English as a Foreign Language (EFL). The participants underwent two experimental conditions: natural L2 reading and isolated sentence reading. The results of the study demonstrated that L2 reading proficiency significantly predicted the total fixation duration and first pass time in both experimental conditions. Additionally, the second pass time and single fixation duration were found to be sensitive to the stimuli presented. Furthermore, the study revealed that B2 learners exhibited less total fixation duration, first pass time, second pass time, and fixation rate compared to B1 learners in both experimental conditions. These findings support the notion that the characteristics of eye movements change as L2 reading proficiency develops. The study also discussed the potential application of eye tracking techniques in future language classrooms to observe and assess L2 learners' reading development.

Vocabulary knowledge plays a critical role in second language (L2) reading comprehension. It influences the efficiency of word recognition and the overall understanding of written texts. Eye movement research provides valuable insights into the cognitive processes involved in L2 reading, including the effects of L2 vocabulary on eye movement patterns.

Numerous studies have explored the influence of L2 vocabulary size on eye movement patterns during reading. Research by Kuperman and Van Dyke (2013) found that readers with larger L2 vocabularies demonstrate faster and more efficient lexical access. They exhibit shorter fixation durations, reduced regression rates, and smoother reading, indicating improved word recognition and comprehension. These findings suggest that a richer L2 vocabulary facilitates faster lexical processing and leads to more fluent and efficient eye movements during reading.

Word frequency, which refers to the frequency of occurrence of words in a language, is another crucial factor influencing eye movement patterns during L2 reading. Studies by Brysbaert and Ghyselinck (2006) and Jiang et al. (2020) have shown that high-frequency words are processed more quickly and accurately compared to low-frequency words. Readers with larger L2 vocabularies tend to have better access to high-frequency words, leading to shorter fixation durations and reduced regression rates. These findings suggest that vocabulary knowledge influences the speed and accuracy of lexical access, thereby affecting eye movement patterns during L2 reading.

Word familiarity, which reflects the degree of personal experience and exposure to a word, also influences eye movement patterns during L2 reading. A study by Williams and Morris (2004) found that readers with greater L2 vocabulary knowledge exhibit faster and more efficient eye movements for familiar words. They also demonstrate better use of contextual support to facilitate word recognition and comprehension. These findings highlight the role of vocabulary knowledge in leveraging prior knowledge and contextual cues to enhance reading fluency and comprehension.

The relationship between L2 vocabulary and eye movement patterns can be influenced by individual differences in reading proficiency and task demands. Studies by Perfetti et al. (2005) and Paribakht and Wesche (1997) have shown that highly proficient L2 readers with extensive vocabulary knowledge demonstrate more efficient eye movement patterns. Additionally, task demands, such as reading for general understanding versus specific information search, can lead to variations in eye movement behaviour. The interaction between vocabulary knowledge, reading proficiency, and task demands highlights the complex nature of eye movement patterns in L2 reading.

The findings regarding the relationship between L2 vocabulary and eye movement patterns have important implications for vocabulary instruction and assessment in L2 contexts. Effective vocabulary instruction can enhance L2 learners' word recognition skills and contribute to more efficient and fluent eye movements during reading. Furthermore, incorporating eye tracking technology into vocabulary assessments can provide valuable insights into learners' lexical access and comprehension processes, informing targeted instructional strategies and individualised feedback.

The reviewed literature indicates that L2 vocabulary knowledge significantly influences eye movement patterns during reading. A larger L2 vocabulary is associated with faster lexical access and smoother reading. High-frequency words, word familiarity, and contextual support also contribute to more efficient eye movements. The relationship between vocabulary knowledge and eye movement patterns is influenced by reading proficiency, task demands, and individual differences.

To summarise, eye-tracking studies in the context of second language (L2) reading have primarily concentrated on factors like language proficiency, exposure to the L2, and differences in language processing across languages. Nevertheless, none of these investigations have specifically delved into the specific patterns of eye movements during L2 reading or provided a comprehensive account of the eye movement metrics associated with varying levels of L2 reading proficiency and exposure, as well as the combined impact of these factors on the development of lexical processing in the L2. To date, little empirical evidence has been presented regarding the effect of L2 proficiency and exposure on the reading performance of L1 reading, especially between Chinese and English scripts. Besides, existing research was based on a limited data sample and few reading items, necessitating further examination and confirmation.

2.7 Research Questions

In this literature review chapter, we have delved into four crucial aspects of eye movements in reading. First and foremost, we explored the fundamental characteristics of eye movements during the act of reading. These movements form the bedrock of our understanding of how our eyes navigate written text. Secondly, we delved into the intricate models of eye movement control in reading, particularly focusing on alphabetic languages like English. These models provide valuable insights into the interplay between oculomotor processes and language comprehension during reading.

An essential point that emerged from our review is the need for expanding these models beyond alphabetic languages like English. Many languages across the world, such as Chinese, present entirely different writing systems. Chinese characters offer a unique opportunity to investigate how eye movement control may vary across distinct writing systems. Over the past two decades, an increasing body of research has emerged to explore eye movements in Chinese reading. Researchers probed into aspects like the absence of spaces between words in Chinese text, which serve as visual cues in alphabetic languages, and how these impact reading and eye movements. Additionally, they explored the challenges posed by the densely written nature of the Chinese language, including issues related to perceptual span and parafoveal lexical processing.

Lastly, our review ventured into the realm of reading English as a second language. The globalisation of education has led to a surge in overseas students studying and residing in English-speaking countries. For these individuals, transitioning from reading in their first language to becoming proficient readers in English entails a unique set of challenges. Their eyes are initially programmed to read in a particular way and acquiring fluency and 'native-like' reading behaviour in a second language necessitates a certain level of language proficiency and lexical knowledge. Moreover, exposure to the second language also plays a pivotal role in reshaping their eye movements and adapting them to the typographical differences between languages, effectively transferring eye movement skills across linguistic boundaries. This chapter thus underscores the richness of research in the field of eye movements in reading and the diverse factors that influence this intricate cognitive process. Based on what we have reviewed in the previous questions, the research question for this study is as follows:

1. What are the different reading patterns, as indexed by fixation durations and landing position, of Chinese students when reading English as L2 and do these patterns change with English proficiency level and amount of exposure to English?

2. Are the patterns we see in the L2 English reading behaviour of L1 Chinese students influenced by properties of their L1 and the way these L1 properties affect reading? Does extended exposure to L2 alter reading behaviour in the L1?

3. Does prior exposure to similar content facilitate the reading process (as indexed by fixation durations) and eye movement target planning (as indicated by landing position)? Does the language of prior reading of similar content, L1 Chinese or L2 English, play a role in this process?

Chapter 3: Methodology

3.1 Ethics Statement

The research involving participants being asked to read texts in English versus Chinese received ethical approval from the Ethics Committee of the University of Birmingham, assuring adherence to ethical guidelines and regulations. Prior to participating in the experiments, all participants were provided with informed consent documents that outlined the purpose, procedures, potential risks, and benefits of the study. Participants voluntarily agreed to take part in the experiments by providing their explicit consent. Full documentation for the ethics review and approval will be provided in Appendix 3A.

3.2 Participants

Forty native Chinese speakers and forty native English speakers, all over the age of 18, were selected as participants for this study. These individuals were students at the University of Birmingham and were recruited based on specific criteria aligned with the objectives and design of the research. For the native Chinese speakers, the inclusion criteria were that they had taken the IELTS exam within the past two years, ensuring a required level of English proficiency. All participants had normal or corrected-to-normal vision.

The participant sample in this study consisted of 40 native Chinese speakers, comprising of 14 males and 26 females. The age range of the Chinese participants was 19 to 32 years, with a mean age of 23.3 years (SD = 2.7). Regarding their educational backgrounds, 9 participants were pursuing undergraduate degrees, 24 participants were engaged in MA programs, and 7 participants were enrolled in doctoral programs.

Amongst the 40 native English speakers, 17 were male and 23 were female. The age range of the English participants varied from 18 to 40 years, with a mean age of 21.5 years (SD = 5.2). Like the Chinese participants, the educational backgrounds of the native English speakers were diverse, with 33 participants being undergraduates, 3 participants pursuing postgraduate studies, and 4 participants engaged in PhD programs.

The data of one Chinese participant had to be excluded from the analysis due to recording issues. As a result, the data of 79 participants (39 Chinese and 40 English) were included in the final analysis[3].

3.3 Language Background Questionnaires and Vocabulary Test

The background questionnaire used in the current study was adapted from Language Background Questionnaire (Li et al., 2006), which was widely used as an enhanced tool in assessing the language learning background in bilingualism or second language (L2) research. The questionnaire employed in this study was adapted into an online format using Google Forms. This digital platform allowed for efficient data collection and facilitated the assessment of participants' language learning history and background, focusing on variables closely relevant to the current investigation, including age of acquisition, language proficiency, and

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[3] It is important to mention that participant recruitment took place during a challenging period, in the national lockdown of 2020, spanning from August 2020 to December 2020. This context added complexity and required additional time and effort in the recruitment process.

language exposure in the United Kingdom. A comprehensive description of the language background questionnaire can be found in Appendix 3D, providing detailed information on its structure and content.

Chinese participants (English as L2) The questionnaire administered to Chinese participants encompassed various demographic questions to gather relevant information. These questions included inquiries regarding age, gender, and the highest level of education achieved. To assess participants' language proficiency, a series of language history questionnaire items were included, which aligned with previous studies and the extensive research on second language acquisition (Park & Ziegler, 2014). Participants self-reported their language proficiency and background by providing details such as their second language (L2), age of initial exposure to English, age at which they began reading in English, years of formal education in English, and scores from the International English Language Testing System (IELTS), a standardised English proficiency test taken within the last two years. The IELTS scores encompassed the overall band score as well as individual scores for listening, reading, writing, and speaking. Additionally, participants reported their duration of residence in the United Kingdom, where the L2 is predominantly spoken. By collecting these comprehensive details, we aimed to obtain a profile of the participants' language background and proficiency levels.

English participants (English as L1) The questionnaire administered to English native speakers (see Appendix 3E) was an adapted and simplified version of the questionnaire originally designed for Chinese participants. At the outset, participants were requested to provide demographic information, including their age, gender, and highest educational attainment. Subsequently, the questionnaire delved into inquiries concerning their native language (specifically whether it is English or not). Through the collection of these crucial details, our aim was to gain insights into the language background and reading practices of English native speakers, enabling a comparative analysis of their eye movement patterns during reading tasks with the Chinese participants. This approach facilitated the examination of potential differences and similarities in eye movements between the two groups, ultimately contributing to a comprehensive understanding of the factors influencing reading processes across different language backgrounds. Basic proficiency level information is presented in Table 3, with respective means and standard deviations (SD).

Table 3

Summary of Chinese participants' IELTS scores

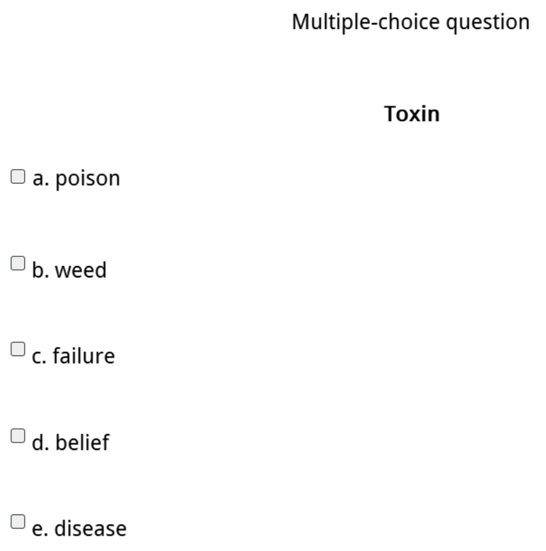
Language background	Mean	SD
Speaking	6	0.62
Listening	7	0.58
Reading	7	0.73
Writing	6.0	0.51
Overall	6.5	0.46

To gauge participants' vocabulary proficiency, we employed a computerised adaptation of the vocabulary subtests from the Nelson-Denny Reading Test (Brown et al., 1993). The Nelson-Denny Reading Test is a well-established standardised assessment of adult reading skills, as noted by previous studies such as Hersch and Andrews (2012).

This test aimed to measure participants' receptive vocabulary size in written English. This computerised task included 30 items consisting of a target word and five alternative words or short phrases. Participants selected which option corresponded most closely to the target’s meaning. During the vocabulary test, participants were required to select the most appropriate choice amongst five-alternative forced choice (5AFC) answers that closely matched the meaning of the target word provided. An example of a vocabulary test question can be seen in Figure 2. The test consisted of a total of 30 words, covering a range of lexical items. On average, the duration of the vocabulary test was approximately 10 minutes, allowing participants sufficient time to consider and respond to each item.

Figure 2

An example of vocabulary size test displayed on OpenSesame



3.4 Clustering Chinese Participants

As we mentioned in the research questions, we aim to see how the eye-movements in L2 reading differ as the L2 proficiency level and L2 exposure varies. Chinese participants reported their latest IELTS scores (including IELTS overall score, IELTS reading score, IELTS listening score, IELTS writing score and IELTS speaking scores), and durations of their stay in the UK. Besides, participants did a vocabulary size test in English. This gave us data that is correlated, as is presented in the next section. To address this issue, we applied Principal Component Analysis (PCA) to a subset of variables that are most important for the purpose of the current study: the IELTS overall score, the IELTS reading score, the scores in the vocabulary size test and the duration of staying in the UK[4]. The remaining variables were excluded to reduce the severity of multicollinearity. PCA gave us the common and independent components of participants' L2 skills. We applied Cluster Analysis to establish groups of participants given their scores on extracted principal components.

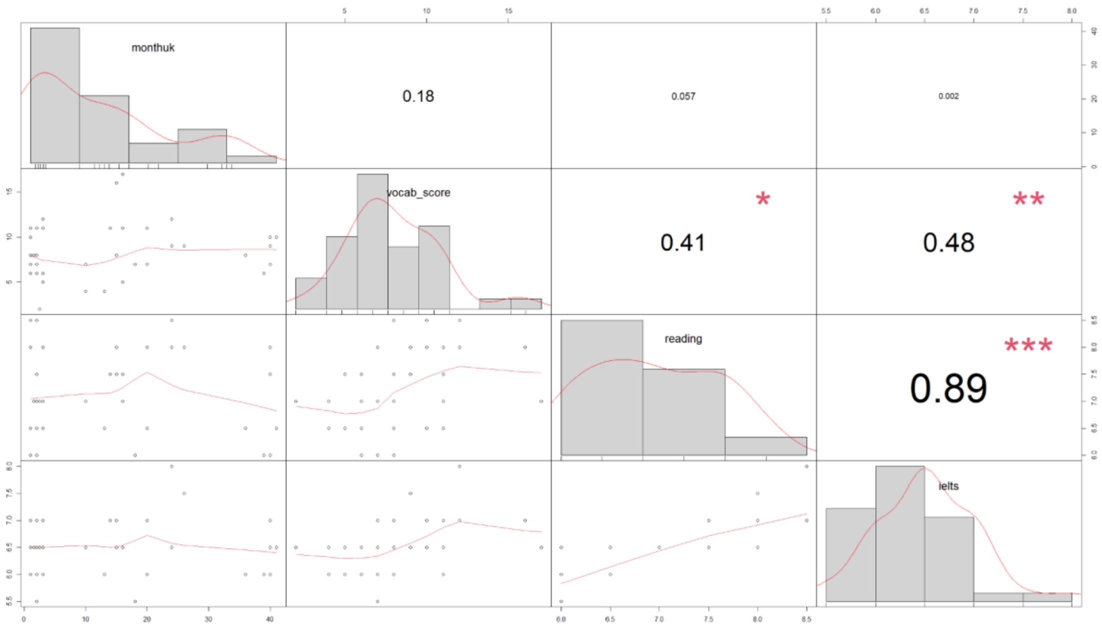
Correlation analyses We conduct the Spearman's rank correlation test to examine the relationships amongst variables. We opt for the Spearman test over the Pearson test because the former does not require the assumption of normal distribution, making it suitable for data that is not normally distributed. Results presented in Figure 3 reveal the relations between the four main variables we were interested in. As the results

[4] Note that during the initial stages of data analysis, predictor variables associated with proficiency were handled as continuous independent numeric variables for integration into the models. Nevertheless, due to their strong intercorrelation and for statistical considerations, Principal Component Analysis (PCA) was employed to address this matter because it allowed us to reduce the dimensionality of our dataset while preserving as much of the variance in proficiency-related variables as possible.

indicate, the correlation between the IELTS overall score (ielts) is significantly and highly correlated with the IELTS reading score (reading). More specifically, the Spearman's rank correlation rho between ielts and reading is positive, statistically significant, and very high (rho = 0.89, S = 1114.98, p < 0.001). There are also significant correlations between the vocabulary size scores and the IELTS reading score and IELTS overall score respectively. The Spearman's rank correlation rho between vocabulary size scores and the IELTS reading scores is positive, statistically significant, and high (rho = 0.41, S = 5859.58, p < 0.05). The Spearman's rank correlation rho between the vocabulary size scores and IELTS overall scores is positive, statistically significant, and high (rho = 0.48, S = 5131.41, p < 0.01).

Figure 3

Correlations between four variables indicating language proficiency and L2 exposure



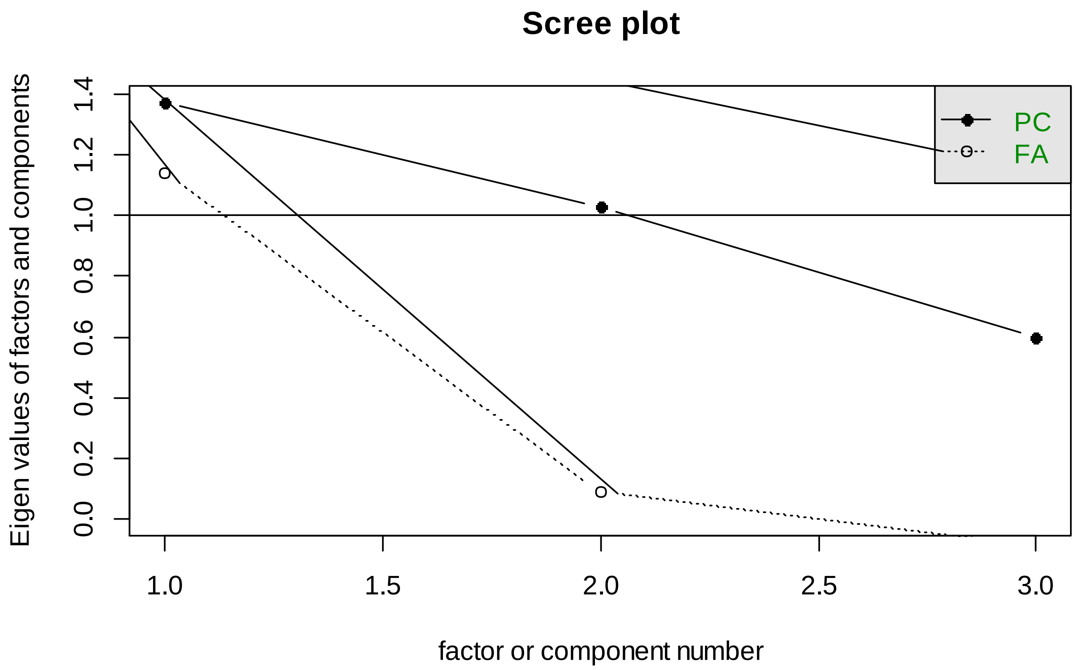
Note. The asterisk (*) signifies a significance level of 0.05. Two asterisks (**) denotes a higher level of significance, usually at the 0.01 level. Three asterisks (***) represents an even higher level of statistical significance, typically at the 0.001 level.

Principal Component Analysis In the final Principal Component Analysis (PCA), we chose to keep only the reading scores from the IELTS due to their very strong correlation with the total scores. This was in conjunction with the scores from the vocabulary size test and the length of time spent in the UK. To make the structure of the extracted factors or components clearer and more straightforward, which were derived from a group of correlated variables, we applied Varimax rotation. This is a method of orthogonal rotation, which means it aims to maximise the independence or orthogonality between the rotated factors. In other words, after Varimax rotation, the factors should be uncorrelated or have minimal correlation with each other, making them easier to interpret. We run Scree Plot to find the optimal number of factors to be retained for the further analyses.

We checked the number of components we needed to retain using scree plot (Figure 4), which indicated that the first two principal components have eigenvalues greater than 1 (for a detailed explanation, see Kaiser, 1960). These two components all together can explain 81.3% of the chosen variable's variance.

Figure 4

The screen plot based on three variables



Note. The screen plot was created based on three variables which were vocab size scores, IELTS reading scores and months of staying in the UK.

Table 4

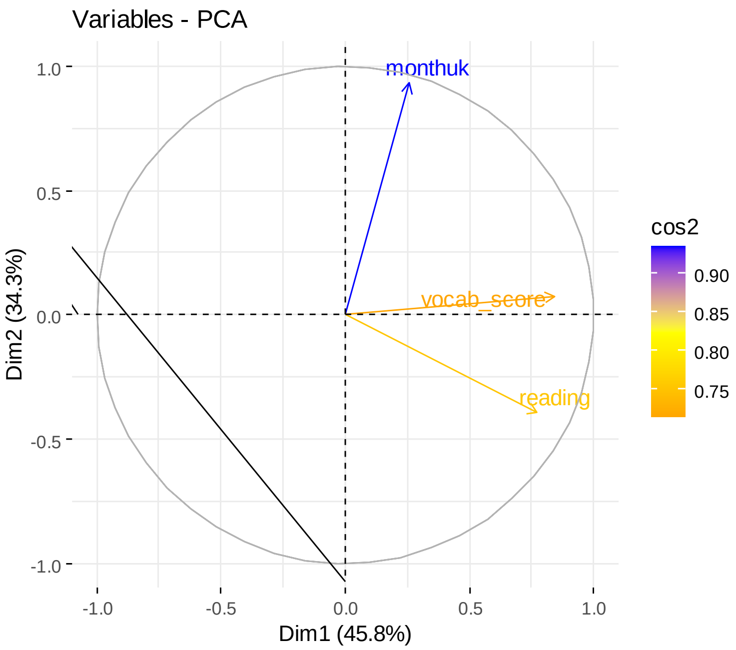
Principal components analysis of three variables

Variable	RC1	RC2	h2	u2	com
monthuk	0.02	0.97	0.94	0.06	1.0
vocab_score	0.80	0.28	0.71	0.28	1.2
reading	0.85	-0.19	0.75	0.25	1.0

From Table 4 we can find that the first principal component has large association with vocab_score (participant's scores in the vocabulary size test) and reading (participants' IELTS reading scores), so this component primarily measures the vocabulary size scores and the IELTS scores of Chinese participants. The second component has large positive association with the monthuk (participants' duration of staying in the UK), so this component primarily measures the durations of participants staying in the UK. The final solution is presented visually in Figure 5.

Figure 5

The loading plot indicating the results for the first two components



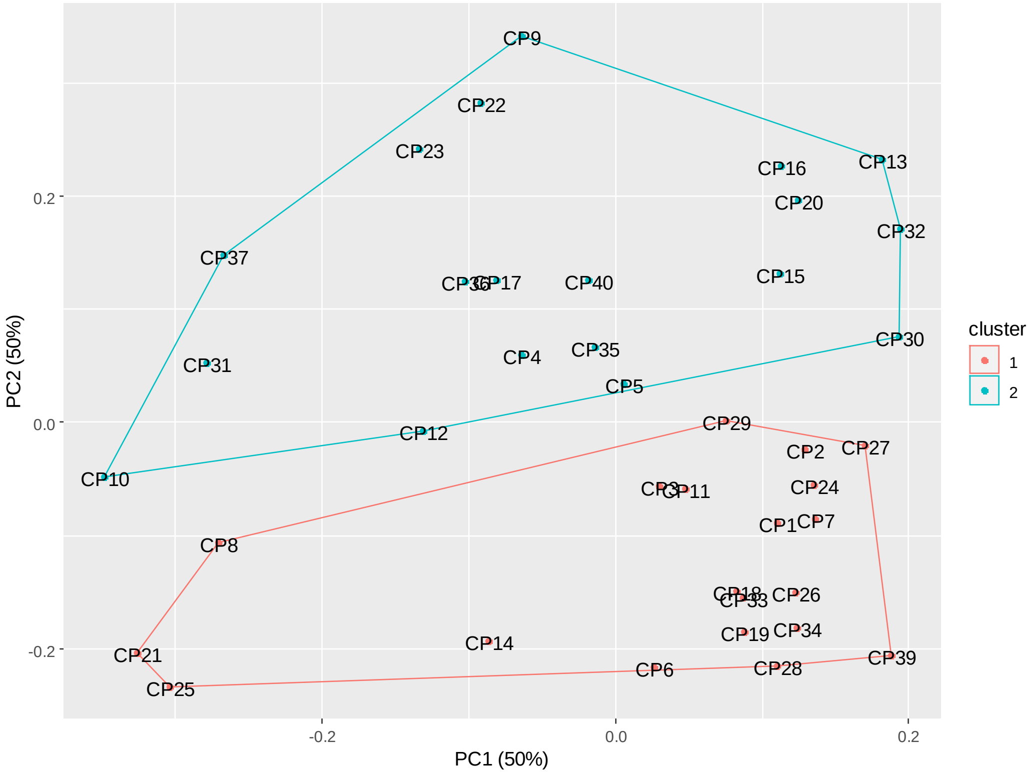
Using PCA scores, we generated two new variables PC.VocabAndReading and PC.MonthsInUK to represent the L2 proficiency and exposure of 39 Chinese participants in this study.

Clustering Analysis. We executed k-means in R with the help of the kmeans function. Here we presented the results of the kmeans which illustrates the clusters. As the result shows, there are 20 and 19 participants in each cluster. We also provide an illustration of the clusters in Figure 6.

```
K-means clustering with 2 clusters of sizes 20, 19

Cluster means:

  PC.VocabAndReading PC.MonthsInUK

1          -0.8054983    -0.2103407

2           0.8478929     0.2214113

Clustering vector:

 [1] 1 2 1 2 2 1 2 2 2 1 1 1 2 1 2 2 1 1 1 1 1 1 1 2 2 2 1 1
2 2 2

[32] 1 2 2 2 1 1 1 2

Within cluster sum of squares by cluster:

[1] 22.23051 25.31711

 (between_SS / total_SS = 37.4 %)
```

Figure 6

Clustering analysis result based on 39 Chinese participants



Based on the result of the PCA and the clustering analysis, we divided Chinese participants into 2 groups with 19 in the Advanced group and 20 in the Upper Intermediate group. Please see the table in Appendix 3F for detailed grouping information of Chinese participants.

3.5 Reading Stimuli

3.5.1 English Reading Materials

The English text materials consisted of short excerpts sourced from online news articles. The selection of these specific texts was driven by the objective of ensuring the readability of the materials. Among the 29 items, five were designated as practice excerpts, serving multiple purposes. Firstly, they were utilised to assess the accuracy and reliability of the eye-tracking system calibration. Secondly, they aimed to familiarise participants with the format, difficulty level, and types of questions encountered in the reading materials.

A comprehensive list of the reading stimuli utilised in the experiments can be found in Appendix 3B for reference. This appendix provides detailed information regarding the specific excerpts employed in the study.

To ensure the familiarity of the readers with the chosen topics, we adhered to three guiding principles:

1. The topics selected pertained to current events. Examples included news related to Covid-19, the garbage sorting policy in Shanghai, and the provision of 5G mobile phones.

2. The topics focused on either China or the UK. Illustrations of such topics encompassed China's Mars Mission, Disneyland in Shanghai, and the pay gap in the UK.

3. The topics delved into everyday life. Instances encompassed subjects such as Facebook, international tourists, working in an office setting, and dogs.

By adhering to these principles, we aimed to ensure that the chosen topics were relevant, relatable, and engaging for the readers, fostering their active participation and comprehension during the study.

To enhance the readability of the English materials for Chinese participants, we sought the expertise of three linguists who meticulously examined the reading stimuli. Their task was to identify words or phrases that might pose challenges for Chinese learners of English and suggest alternative terms that were easier to comprehend while preserving the intended meaning. Here is an example to illustrate this process as follows.

The original word or phrase "curb" was replaced with the simpler term "limit", while the word "plunged" was substituted with the more accessible term "decreased".

By employing this approach, we aimed to ensure that the English reading materials were more comprehensible for Chinese participants, facilitating their engagement with the content and reducing potential language-related barriers during the study.

Original version: Widespread travel restrictions and the closure of airports and national borders to ***curb*** *the spread of the virus had* ***plunged*** *international tourism into its worst crisis since records began in 1950, the UN tourism body said in a statement.*

Simplified version: Widespread travel restrictions and the closure of airports and national borders to ***limit*** *the spread of the virus had* ***decreased*** *international tourism into its worst crisis since records began in 1950, the UN tourism body said in a statement.*

We also slightly modified some of the words and phrases in the English reading materials to make them more concise. Main changes were made in the following aspects:

1. Arabic numerals were changed into English written (spelled-out) numerals (e.g., 24 into twenty-four).

2. Short paragraphs were merged into one larger paragraph.

The excerpts were 44 to 98 words long (M = 70.7, SD = 12.9) and were shown in a single paragraph, fitting one display presentation. We randomly added a yes/no comprehension question after some paragraphs to make sure participants read the materials carefully and comprehended the sentences. In total, every participant answered 6 comprehension questions. An example about a text and the comprehension question can be found in Appendix 3C.

3.5.2 Chinese Reading Materials

We ensured that the Chinese reading stimuli covered topics similar to those in the English texts by conducting online searches using the same keywords. However, slight modifications were made to some sentences to enhance the conciseness of the Chinese versions. These modifications aimed to create Chinese reading materials that closely mirrored the content of the English texts, while ensuring that they were concise and presented in a cohesive manner. Consistently with English excerpts, the following adjustments were made:

1. Arabic numerals were replaced with Chinese numerals. For instance, "2020" was transformed into "二零二零".

2. Several short paragraphs were combined into a single, larger paragraph to maintain the coherence and flow of the text.

The passages varied in length from 73 to 220 Chinese characters (M = 143.9, SD = 36.1) and 38 to 71 Chinese words (M = 55.9, SD = 10.3). They were presented in a single paragraph format on the screen. Further information about the reading materials can be found in Appendix 3B.

3.5.3 Similarity Scores Between English and Chinese Texts

As mentioned earlier, to ensure comparability between the Chinese and English reading materials, we carefully selected Chinese stimuli that closely matched the topics of the English texts by conducting online keyword searches. To address potential biases associated with the order of reading Chinese and English texts, we employed a balanced design wherein half of the Chinese participants first read texts in their native language (L1) and then proceeded to read English texts as their second language (L2), while the other half followed the reverse order.

In order to assess the degree of similarity between the Chinese and English texts, we sought the assistance of three Chinese native speakers who were concurrently studying linguistics and are fluent in English. These raters were provided with both Chinese and English texts that covered identical topics and were requested to rate the similarity between the two versions using a scale ranging from 1 to 5. A rating of 1 indicated complete dissimilarity, while a rating of 5 indicated a literal translation. The average rating for each text was computed based on the independent ratings provided by the three raters. These average scores represented the similarity scores, reflecting the extent of similarity in translation between the Chinese and English texts.

The overall average similarity score for all 24 texts was calculated to be 3.53 out of 5 (SD = 1.48) with a minimum score as 1.33 and maximum as 5. It is important to note that a higher score indicates a greater degree of literal translation between the two texts in English and Chinese, indicating a closer correspondence in terms of content and meaning. This assessment of similarity between the texts provided valuable insights into the degree of correspondence between the Chinese and English versions, thereby informing the subsequent analyses of reading behaviours in the study.

3.5.4 Word Segmentation

To ensure optimal alignment between the English and Chinese reading tasks, we employed word-based Interest Areas (IA). Subsequently, a second Chinese native speaker, possessing a PhD in applied linguistics and demonstrating high proficiency in both Chinese and English, performed a meticulous review of the word segmentation. This process aimed to achieve a high level of inter-rater reliability, which resulted in approximately 95% agreement between the two Chinese natives. Consequently, the word segmentation was configured accordingly for the IA setup.

To elucidate the word segmentation procedure and exemplify the reading stimuli integrated into the Experiment Builder software[5], we provide the following illustration:

For instance, consider the sentence "他在图书馆借了一本有趣的小说" (He borrowed an interesting novel from the library) in Chinese. The word segmentation

[5] Experiment Builder, by SR Research Ltd., is a software for creating behavioural and eye-tracking experiments, widely used in cognitive and visual research.

process involved identifying and separating individual words within the sentence, resulting in segmented units such as "他" (He), "在" (at), "图书馆" (library), "借了" (borrowed), "一本" (an), "有趣的" (interesting), and "小说" (novel).

The segmented words were then added as reading stimuli within the Experiment Builder, ensuring accurate presentation and manipulation of the text during the experimental tasks.

Here is an example with the materials used in this study.

The Original Chinese text

读一本有趣的书，当你沉浸于书中有趣的点子，或者和作者产生共鸣的时候，那种有一座桥搭进心灵的感觉让人豁然开朗。这个时候生活中一切的烦恼和紧张都会被忘记，这也是很多书虫热爱读书的一个重要原因。读书越多的人，词汇量越大，逻辑越清晰，表达能力越强。结果是更加自信，在工作中和生活中能够得到更多的认可。

The word based segmented Chinese text

*读*一本*有趣*的*书，*当*你*沉浸*于*书中*有趣*的*点子，*或者*和*作者*产生*共鸣*的*时候，*那种*有*一座*桥*搭进*心灵*的*感觉*让人*豁然开朗。*这个*时候*生活*中*一切*的*烦恼*和*紧张*都*会*被*忘记，*这*也是*很多*书虫*热爱*读书*的*一个*重要*原因。*读书*越*多*的*人，*词汇量*越大，*逻辑*越*清晰，*表达*能力*越强。*结果*是*更加*自信，*在*工作*中*和*生活*中*能够*得到*更多*的*认可。*

Note that the participants did not see these * and this was done for stimuli preparation.

3.6 Apparatus

For the eye-tracking phase of the study, participants' eye movements were recorded with an EyeLink Portable Duo system (Version: 6.10.01). We prepared a table clamp chin cup head support to avoid participants moving heads during data collection. We used head-stabilised monocular recording, for the dominant eye, in pupil-only mode. The eye tracking system sampled at the rate of 500 Hz. The presentation display screen was 24-inch. Participants were seated 45cm away from the display screen in a comfortable chair that was positioned at a fixed distance from the screen. The lighting conditions in the room were carefully controlled to ensure consistency for all participants in the study. The illumination remained constant throughout the experiment, ensuring that variations in lighting did not introduce any confounding effects on the measurements. Additionally, precautions were taken to position the eye tracker in a way that avoided direct exposure to overhead lights. This was done to prevent any potential issues with the eye tracking accuracy, as direct overhead lights can sometimes interfere with the tracking process. By maintaining a stable and controlled lighting environment and placing the eye tracker strategically, the study aimed to minimise any potential disturbances or biases that could arise from inconsistent or problematic lighting conditions.

For stimulus presentation and data acquisition, we utilised applications generated from Experiment Builder software. The reading materials were displayed with black letters on a white background, employing the Courier New font in Normal style, and a font size of 18. To enhance readability and minimise visual strain, we employed double vertical spacing between lines of text. The presentation of single excerpts and English questions was arranged in the vertical position, utilising a screen resolution of 1024*768 pixels. These careful formatting choices aimed to optimise legibility and ensure consistency across stimuli for all participants. For eye movement data acquisition, visualisation and results exporting, Data Viewer software 4.3.210 was used.

3.7 Procedure

The entire study was conducted within a quiet laboratory situated on the university campus. Upon arrival, participants were provided with detailed instructions regarding the experiment and a concise overview of the eye-tracking device employed. Furthermore, they were presented with an information letter explaining the study's purpose and procedures, after which they signed a consent form indicating their willingness to participate. To ascertain participants' dominant eye, we employed the following method.

Initially, a cross (+) sticker was affixed to a door. The participant then positioned themselves approximately two meters away from the door and extended one arm, with the thumb of that hand holding upright. Subsequently, while maintaining both eyes open, the participant focused on the cross placed on the door, covering their thumb with the cross. This was followed by the alternating closure of one eye at a time. Ultimately, participants indicated which eye corresponded to the instance where their thumb was directly aligned with the cross on the door while the other eye remained closed. By employing this approach to determine participants' dominant eye, we ensured accurate calibration of the eye-tracking system to capture precise eye movement data throughout the study.

Subsequently, participants took a seat and positioned their heads on the chin-up head support to ensure stability during the eye-tracking session. To establish accurate and reliable eye gaze measurements, we conducted an initial calibration of the eye-tracking system at the outset of the experiment. As necessary, we validated the calibration to maintain the quality of the data throughout the experiment. The calibration process involved a nine-point calibration, a standard method for reading multi-line text. This method facilitated accurate mapping of participants' eye movements and enabled precise eye tracking during the experiment.

Following the completion of calibration and validation procedures, participants were prompted to initiate the practice trial by pressing any button on the input device. To ensure accurate eye-tracking measurements, we implemented a drift correction procedure. The drift correction point was positioned at 50 pixels left and 85 above from the first character in a given paragraph. This placement aimed to minimise any potential systematic errors and assist in maintaining the accuracy of eye gaze measurements throughout the subsequent task.

Participants were told to read the story only once and at their own pace to understand the texts. They were told that the first five excerpts were only read for practice.

Participants were given prior notice that comprehension questions would be part of the study, but they were not provided with specific details about which texts or at what points these questions would be presented. The comprehension questions were answered with 93% average accuracy with English participant in the English reading study. The average accuracy with Chinese participants in the English reading study was 95% and 93% in the Chinese reading study.

After reading each text displayed on the screen, participants in the study were instructed to press the space key on the keyboard positioned in front of them to proceed to a new screen page where a comprehension question was presented to them. In cases where no question was associated with a particular excerpt, pressing the space key would initiate the calibration stage. Participants were specifically instructed to use the Z key located on the left side of the keyboard to indicate a wrong answer and the M key on the right side to indicate a correct answer, adhering to the commonly adopted response format for comprehension questions. To ensure the accuracy of the eye-tracking data collection, participants' head movements were closely monitored during the reading task. If any head movement was detected that could potentially interfere with the reading process or data acquisition, a calibration correction was promptly administered.

Both the Chinese and English reading experiments comprised two distinct versions, namely version 1 and version 2. These versions encompassed a shared set of five practice trials, which were designed to familiarise participants with the experimental procedures. Subsequently, a total of 24 experimental trials were prepared for data collection.

In version 1 of the experiments, the experimental trials were presented sequentially, commencing from e1 and concluding with e24. Conversely, version 2 employed a reversed order of presentation, where the experimental trials were displayed in a counterbalanced manner, starting from e24 and concluding with e1. This counterbalancing of wordorder aimed to account for any potential biases associated with the sequence of stimulus presentation.

Amongst the 40 Chinese participants, 20 individuals participated in the English reading experiment version 1, while the remaining 20 participants engaged in version 2. Similarly, 20 English participants were assigned to the English reading experiment version 1, while another 20 English participants were assigned to version 2. Likewise, 20 Chinese participants performed the Chinese reading experiment version 1, while the remaining 20 Chinese participants completed version 2. To further account for the potential influence of reading order, 20 Chinese participants initially undertook the Chinese reading experiment, while the remaining 20 Chinese participants began with the English reading experiment.

By implementing this systematic counterbalancing strategy, we aimed to control for potential confounding factors related to reading order and ensure the integrity and validity of our findings when comparing the reading performance across different language conditions and participant groups.

The duration of the reading task for Chinese participants varied from 30 minutes to 40 minutes due to their different reading speeds. The duration of the experiment for English participants was around 10 minutes.

After the paragraph reading experiment, both groups did a vocabulary test. The whole study ended with a questionnaire mainly with respect to the social-geographic information and reading habits. Chinese participants also answered a list of questions about their demographic background, which includes age, gender, current degree, duration of staying in the UK (in months), and their latest IELTS scores. Native English speakers answered questions about their age, gender, current degree, foreign language learning experience, and reading habits. Full versions of the questionnaires for the Chinese and English participants can be found in Appendix 3D and Appendix 3E.

After all these tasks, participants signed the form to confirm that they received vouchers to compensate for their time. The total experimental duration for participants who are native Chinese speakers was about 90 minutes, and for participants who are native English speakers was approximately 70 minutes.

3.8 Eye-Movement Variables

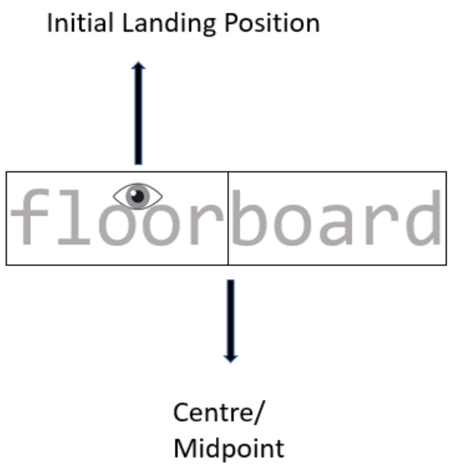
In the English reading study, the interest areas are each English words and, in the Chinese, reading study, the interest areas are segmented words as explained in Section 3.5.4 on Word segmentation. Our analysis focuses on the durations and landing positions on the currently fixated word. Here we will provide a consistent terminology on what we mean the currently fixated word and the neighbouring words. To this end, we refer to the word currently fixated as word N, to the word to the left of it as word N-1 (the previous word), and to the word to the right of it as word N+1 (the next word).

The study focuses on four main eye-movement measures as dependent variables related to durations and saccadic targeting in reading. The first one is the first fixation duration. The first fixation duration in a particular region of text, as we might expect, is simply the time the reader spent initially fixating in that region. The second one is the gaze duration which is defined as the sum of all the fixations made in a region until the eyes leave the region either to the left or to the right. The third dependent variable is the total reading time which sums all fixations made within a region of text, including those fixations made when re-reading the interest area.

The fourth dependent variable is the Relative Landing Position (RLP). The relative landing position was calculated as the midpoint of the Interest Area (the X coordinate indicating horizontal position on screen) minus the X position of the first fixation event within the current Interest Area. Here we provide two examples of how we calculate the Relative Landing Position and the relationship between it and the actual initial landing positions of eyes in Figure 7 and Figure 8.

Figure 7

Initial landing position left of a word's centre illustrated

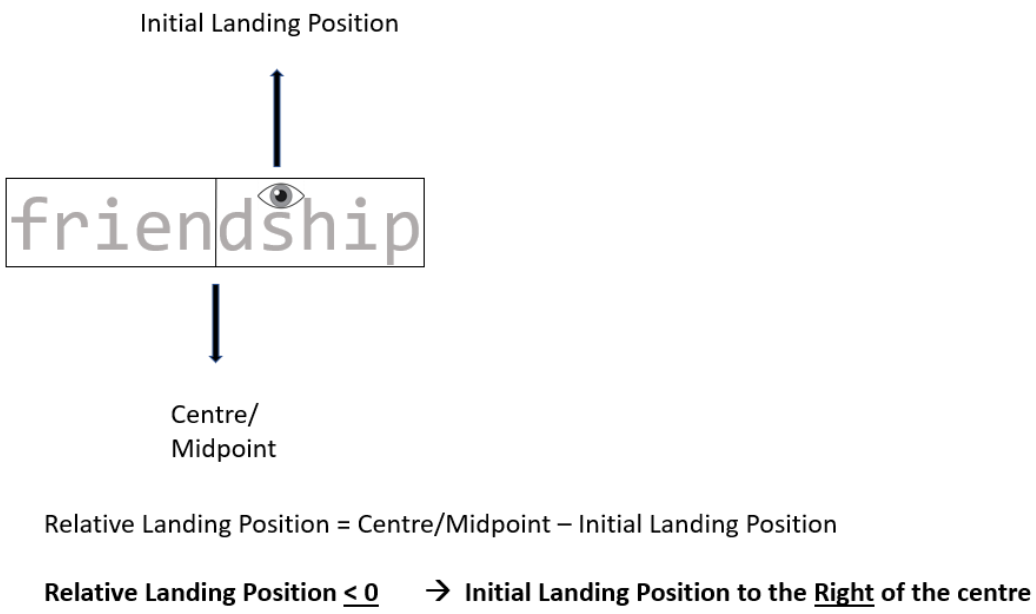


Relative Landing Position = Centre/Midpoint – Initial Landing Position

Relative Landing Position <u>> 0</u> → Initial Landing Position to the <u>left</u> of the centre

Figure 8

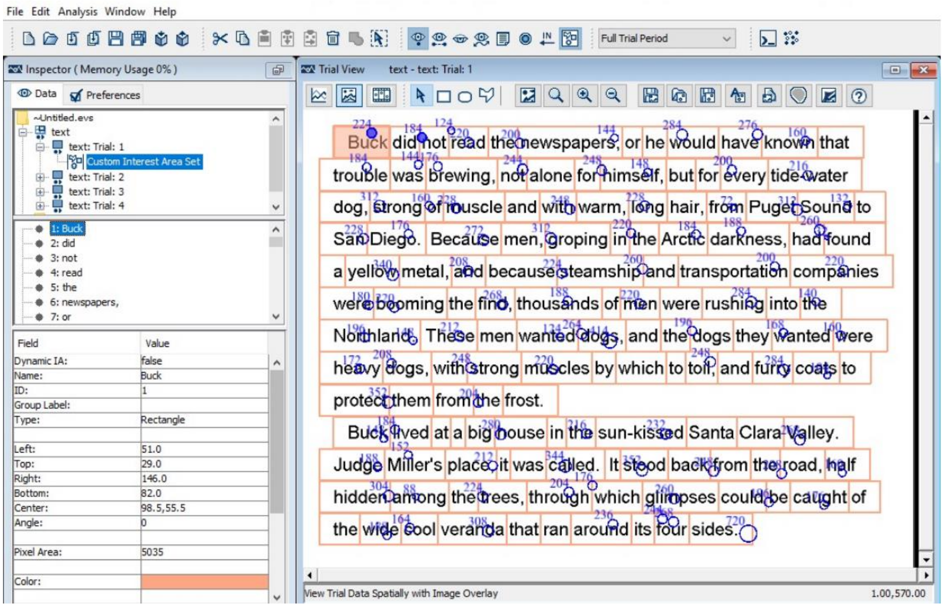
Initial landing position right of a word's centre illustrated.



To better illustrate how we calculated the RLP, we used the Sample Spatial Overlay View of Fixation Events in the manual of EyeLink Data Viewer in Figure 9.

Figure 9

A sample text display overlaid with Interest Areas



Note. This sample is a sample from the EyeLink Data Viewer User Manual (SR Research Ltd. Oakville, 2021)

As shown in the example, we set each word in the reading text as an Interest Area (IA). In the first IA, the word is 'Buck'. From the left-bottom pane (Figure 10) we can see the left value is 51.0, which indicates the X-coordinate of the left-most edge of the rectangular interest area.

Figure 10

The left-bottom pane of the sample text display overlaid with Interest Areas

Field	Value
Dynamic IA:	false
Name:	Buck
ID:	1
Group Label:	
Type:	Rectangle
Left:	51.0
Top:	29.0
Right:	146.0
Bottom:	82.0
Center:	98.5,55.5
Angle:	0
Pixel Area:	5035

Similarly, the value of the Right indicates the Y-coordinate of the left-most edge of the rectangular interest area. We calculated the midpoint of the current IA by the equation:

Midpoint = x-coordinate of the Left + ((x-coordinate of the right - x-coordinate of the Left)/2).

Then, with the help of the Data Viewer, it reports the x-coordinate of the fixation in Buck (indicated by the blue circle with a fixation duration of 224 ms). We used the value of the midpoint of that IA minus the x-coordinate of the fixation in Buck. Then, we had the results of the RLP of the fixation in IA 'Buck'. If the value of RLP of the fixation in the IA 'Buck' is positive, it means that the fixation was made to the right of the midpoint/centre of the word; if the value of the RLP of that fixation in the first IA "Buck' is negative it means that the fixation was made to the right of the centre of the word.

3.9 Data Preparation

3.9.1 Data Preparation of the English Reading Study

The complete English reading dataset contains three main parts: eye-movement recordings, the vocabulary test scores and the results of the questionnaires. Regarding the results of the English reading experiment, we output the reports using the software Data Viewer. Regarding the eye-movement data, we removed words that were not fixated as we focus on durations and landing positions on words that received at least one fixation[6]. We moved first fixation durations that were shorter than 60 ms or longer than 1000 ms from analysis because such extreme values are likely to be associated with artifacts, blinks, or data recording errors rather than meaningful cognitive processes related to reading (Ashby et al., 2005; Yan, Kliegl, Shu, et al., 2010; Yen et al., 2009). In line with our data preprocessing procedures, gaze durations exceeding 1200 ms and total reading times surpassing 2000 ms were removed from the dataset because such extreme values are likely to be associated with artifacts, blinks, or data recording errors rather than meaningful cognitive processes related to reading or comprehension. Removing these outliers helps ensure the reliability and accuracy of our data analysis. Additionally, we only retained relative landing positions falling within the range of -100 to 100 because this range encompasses the critical area around

[6] Note that in the initial data analysis phase, words skipped in the English reading task were excluded, given the focus of this study on fixation durations and landing positions. However, we did examine eye movement data concerning skipping behaviours, such as the varying rates of skipping between L1 and L2 readers, and the differential skipping probabilities of certain word types (e.g., articles, prepositions) by L1 and L2 readers. Although these observations are not included due to the specific focus and word limit of this thesis, they will be elaborated upon in a subsequent publication. Similarly, words that were skipped in the Chinese reading study were also removed from analysis in this thesis.

the target word or region during reading. Deviations beyond this range may indicate gaze shifts that are less likely to be related to the immediate processing of the text and could introduce noise into our data.

Besides the eye movement data, in the dataset of the English reading experiment, we included the following variables:

1. Participant_ID (CP 1 to CP40, and EP1 to EP40[7]), as the indicator of the participant.

2. Trial_Index to indicate the number of the text the participant read (1 to 24), IA_LABEL to present the word and IA_ID (Word_ID) to indicate the sequence of the word in a text. Additionally, we need to be able to control the order of words in a text, as well as the sequence of texts in a reading experiment, affects the fixations on word N. We address these questions by creating a new variable called Word_Story_Order, a variable that is a text-level property. Word_Story_Order is created based on two variables indicating the order of words (IA_ID) and the order of stories (Trial_Index) to investigate the possible word order effect. IA_ID indicates the order of a given word inside a text, whereas Trial Index indicates the order in which a text is displayed for a certain participant according to the experiment design. IA_ID is nested in Trial Index because words are contained as reading stimuli in stories. Recall that there are a total of 24 short texts included as reading stimuli. Concerning the length of each text, the longest test has 116 words. Since IA_ID is at most a three-digit number, the value of

[7] CP represents Chinese Participants. EP represents English participants.

1000 multiplies Trial_Index plus IA_ID can uniquely identify the value of Trail_Index and IA_ID. Therefore, we multiplied Trial Index by 1000 and then added the number of IA_ID (mathematical addition) to create a new variable Word_story_order. For instance, 5G is the third word in the eleventh text read by a participant; its word story order is 11003; chocolate is the 78th word in the 23rd text read by a participant; its word story order is 23078.

We added this variable Word_story_order to test the word order effect. This effect is named after the end-of-sentence effect. Comparing the fixation durations for constituents in different positions of the sentence revealed significantly longer fixation durations for constituents which were placed at the end of the sentence (Konieczny et al., 1995). This effect is consistent with the frequently reported sentence wrap-up effect which refers to processes during which a final interpretation of the sentence is computed after it has been read (see Just & Carpenter, 1980). However, little is known about the end-of-story effect and end-of-study effect. Our hypothesis is that readers read quicker towards the end of the text because the context and what they have already read and comprehended aid them in predicting and guessing the following words. Additionally, they may initially have been intimidated by reading on a screen with an eye-tracker in front of them. As the reading experiment proceeds, they habituate to the experiment. Another possibility is that as participants read more, they tended to be fatigue hence had shorter durations towards the end of the reading experiment. Please note that henceforth in this thesis, the effect initially identified as Word_story_order will be described as the word order effect.

3. We also added variables at the word level, including the length and the frequency[8] of the word. We did this to make the list of potential predictors more comprehensive. We introduced two new variables: the length of the English word and its frequency.

4. Based on the design of the current study, we also added the information about the length and the frequency of the previous word and the next word (Heister et al., 2012).

5. A dummy variable GroupOrder. In the study, participants from China were randomly assigned to different groups for the experiment. Half of the participants read the materials first in Chinese and then in English, while the other half followed the reversed order, starting with English and then moving on to Chinese. To keep track of the groups and reading orders, a variable called "GroupOrder" was coded. This variable serves as a dummy variable, indicating both the group a participant belongs to and the reading order they followed. For example, CP1, the first Chinese participant, was in the Upper_Intermediate group and began the experiment with the Chinese reading materials. On the other hand, CP11, the 11th Chinese participant, also belonged to the Upper_Intermediate group but started with reading English texts (the English reading task) first.

With all separate dataset finished, we initiated the first stage by combining all the columns with the eye movement variables based on the column Participant_ID

[8] The data of frequency of words in this study were extracted from British National Corpus (BNC).

(including 39 CP from CP1 to CP 40 by removing CP38, and 40 EP from EP1 to EP40) in all dataset with the *dplyr*[9] (Hadley et al., 2022) function in R. After the data merging process, the overall English reading study dataset contains 139,121 word-based observations of eye-movement recorded from 79 participants reading English.

The second phase of our data preparation encompassed a comprehensive descriptive analysis, focusing specifically on the probability densities of the variables within the scope of this study. To ensure the integrity and reliability of our subsequent statistical modelling endeavours, we took measures to eliminate influential values, i.e., extreme values and outliers. Moreover, variable transformations were employed as necessary to optimise the suitability of the data for statistical modelling purposes, following Baayen and Milin (2010).

We applied Box-Cox power transformation to the data of first fixation duration and gaze duration. The Box-Cox power transformation was a procedure developed by statisticians George Box and David Cox to identify an appropriate exponent (Lambda) to use to transform data into a Gaussian (i.e., Normal) shape (Box & Cox, 1964). The lambda value indicates the power to which all data should be raised to make the distribution of data bell-shaped – that is, Gaussian. The Box-Cox power transformation searches from Lambda = -5 to Lambda = +5 until the best value is found. We applied Box-Cox power transformation on the data of first fixation durations with the Lamba= 0.3592566, and on the data of gaze durations with the Lambda = 1.18767. We used log-

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[9] https://dplyr.tidyverse.org

power transformation to the data of total reading time which is also suggested in Fox and Weisberg (2018).

After the data power transformation (Box-Cox power transformation and log-power transformation), the distributions of all the four eye-movement measures approximated normality. Following the power transformation, the first fixation duration spans from 4.379 to 11.918, gaze durations range between 1.52 and 2.168, and total reading time falls within the range of 4.111 to 7.598. During the final stage of our analysis, we employed Q-Q (quantile-quantile) plots to assess the probability distribution of the four measures under investigation. This visual diagnostic tool allowed us to examine the degree of correspondence between observed data and expected values based on theoretical Gaussian distribution. To ensure the integrity of our dataset and mitigate the impact of potential outliers, we excluded values showing clear indication of being the influential values, either extremes or outliers.

For the first fixation durations, values exceeding 10 were removed, while for the gaze durations, values exceeding 2.1 were excluded. This prudent approach enabled us to focus our analysis on a more reliable subset of data. The range of acceptable values for the first fixation durations fell between 4.379 and 9.991, while the gaze durations spanned from 1.52 to 2.099. Similarly, the range of total reading times was confined within the range of 4.111 to 7.598. After this rigorous data filtering process, we were left with a total of 80,797 observations eligible for further analysis (58%).

3.9.2 Data Preparation of the Chinese Reading Study

As we introduced in the previous sections, Chinese participants did the two reading experiments, both read English texts, and Chinese texts. The data merging process of the Chinese study is similar to the English study. Firstly, we output the results of the eye-movement measures from the Data Viewer of 39 Chinese participants. Note that we removed the data of the CP38 due to major data missing. Besides the four eye-movement measures in reading Chinese, which are first fixation duration, gaze duration, total reading time, and relative landing position. The variable at the text level Word_story_order to test the word order effect was also added for data analysis and modelling. We added the length of the Chinese word (based on character numbers) and its frequency as two word- level variables. Note that the frequency data for Chinese words was sourced from the Chinese Lexical Database (Sun et al., 2018). Since we are also interested in the possible influence of the neighbouring words on the fixations on the currently fixated word, the length, and frequency of the word to the left and the right of the currently fixated word was also added as four new variables.

After the data merging process, the overall Chinese reading study dataset contains 60,060 word-based observations of eye-movement recorded from 39 Chinese participants reading Chinese. Here too, we removed words that were not fixated as we mainly focus on durations and landing positions on words that had at least one fixation. Then, we removed blinks and first fixation durations that were shorter than 60 ms or longer than 1000 ms from the analysis. After this first stage, there were 26,709 observations left for analysis. Same to the process of data normalisation to the data of the English reading study, power transformation was applied to the data of first fixation duration, gaze duration, and total reading time in the Chinese reading study. We applied Cox-Box power transformation to the first fixation duration and gaze duration, and the lambda values were 0.1669407 and 0.07772322 respectively. We used log transformation on the values of total reading time. After the data normalisation, there were 26,438 observations for further analysis. The substantial difference in the number of observations between the English reading study and the Chinese reading study can be attributed to the fact that the latter exclusively includes data from Chinese participants. Furthermore, the high skipping rate observed in the Chinese reading study indicates that a greater proportion of words in the Chinese reading materials were either skipped or not fixated by the Chinese participants. More specifically, the range of the first fixation durations is from 1.992 to 2.908; the range of the gaze durations is from 1.378 to 1.644 and the range of total reading time is from 4.127 to 6.906.

3.9.3 Data Availability Statement

In adherence to the principles of research transparency and open science, all data and code associated with the study presented in this thesis have been uploaded to the Open Science Framework (OSF). The relevant materials are accessible via the link: https://osf.io/bsaud/?view_only=a6b2752286664165b70bd18ff72699db.

This step is taken to facilitate a thorough and transparent evaluation of the findings. Examiners have full permission to download the necessary data and code for the purpose of evaluating this study. This practice supports the wider scientific goal of fostering a collaborative and transparent research environment, enabling further research and validation.

Chapter 4: English Reading Study - First Fixation Duration

Continuing from the established understanding that fixation durations are indicative of cognitive processing, contemporary research has nuanced this perspective by acknowledging the decoupling of processing time from oculomotor behaviour (Pollatsek et al., 2006; Reichle et al., 1998a). For instance, the parafoveal-on-foveal effect suggests that the processing of a word can begin even before it is directly fixated upon, as information from the parafoveal vision can influence the duration of the subsequent foveal fixation. Additionally, the spillover effect illustrates how the processing effort of previously fixated words can extend the fixation time on the current word, implying a dynamic interaction within the perceptual span that extends beyond the isolated properties of 'word N' (Schotter et al., 2012; Vasilev & Angele, 2017).

Nevertheless, the essence of the first fixation duration as a measure of the initial lexical processing remains a tenet within the field. The first fixation duration is believed to encapsulate the decoding and preliminary integration of a word's meaning within the larger textual context. While this fixation may indeed be influenced by parafoveal preprocessing or prior lexical difficulty, it still serves as a primary index of the cognitive workload demanded by 'word N' (Rayner, 2009a).

In light of these insights, first fixation durations offer a window into the cognitive processes engaged during reading, are normally seen as a highly automatic word recognition and lexical access processes, i.e., extracting orthographic and phonological information (Pollatsek et al., 2006; Rayner, 1998). Longer first fixation durations on a word are generally interpreted as markers of increased cognitive demand, whether due to the inherent complexity of 'word N', or due to integrative processing shaped by its linguistic context. Conversely, shorter first fixation durations tend to suggest a more streamlined cognitive integration, possibly due to higher predictability, ease of decoding, or prior exposure to similar lexical configurations (Kliegl et al., 2006).

In this chapter, we will focus on first fixation durations. The first two research questions addressed in this chapter are as follows:

- RQ1: Are there significant differences between Chinese participants (CP) and English participants (EP) regarding their first fixation durations while reading 24 English texts?

To address the first research question, we explore and visualise first fixation durations of Chinese and English participants to detect whethere there are differences between them concerning the first fixation durations when reading English texts.

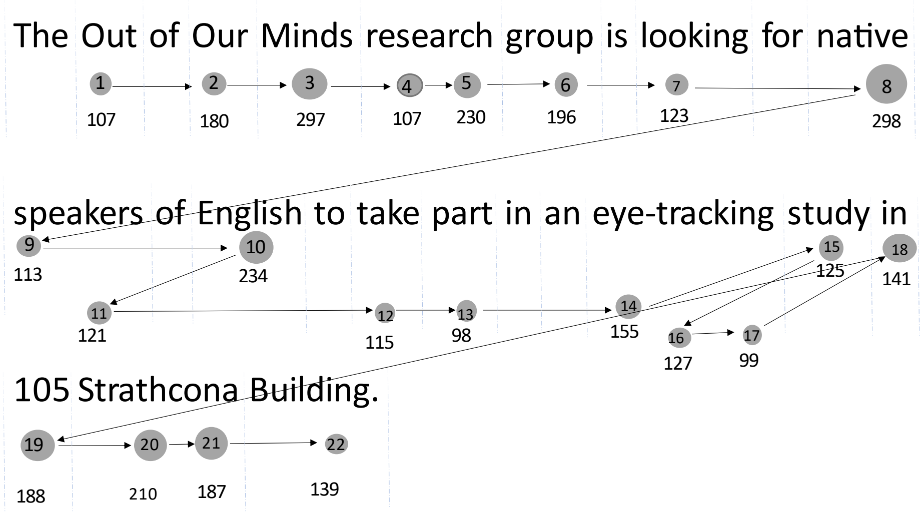
- RQ2: Do CP's patterns of first fixation durations when reading English relate to their English language proficiency levels and exposure?

With regard to the second research question, we aim to establish a link between the eye movement, first fixation durations and Chinese participants' L2 reading abilities, more specifically, their reading fluency and exposure.

We begin by offering an explanation of first fixation durations. First fixation duration in a particular region of text is the time the reader spent initially fixating the region. In Figure 11, first fixations are fixation 4 on the word 'research', fixation 9 on the word 'speakers' and fixation 14 on the word 'eye-tracking', fixation 20 on word 'Strathcona'.

Figure 11

Hypothetical eye-movements (fixations and saccades) during silent reading



Note. Each word is regarded as an Interest Area (IA) with dashed line separating them. Grey circles indicate fixations and arrows show saccades with various directions and lengths. Numbers (1-22) in circles show the order of fixations (in millisecond, such as 107 ms, 180 ms etc.). Fixations were presented below words instead of on words for the purpose of a better presentation. This is an edited format of the figure based on Pellicer-Sánchez (2016), and a more detailed demonstration can be found in Appendix 3G.

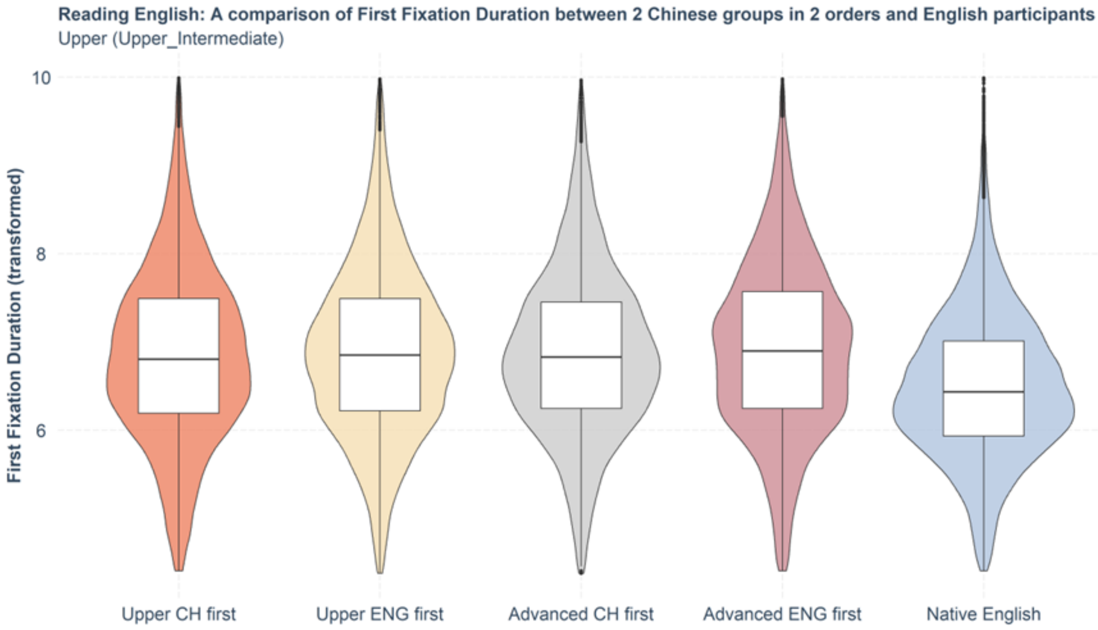
4.1 Preliminary Data Analysis

Remember that the Chinese participants were exposed to reading stimuli in both Chinese and English, but the sequence in which they encountered these stories varied. A group of 19 Chinese participants initially engaged with the Chinese material (that is, they commenced with the study focusing on reading in Chinese), while another set of 20 participants started by reading the English content (meaning they undertook the study on reading in English first). Upon first approaching the stories in Chinese, their native language, the Chinese readers would have grasped the main essence of the texts.

This experience could potentially shape their reading patterns, particularly the initial eye movements, when they switch to reading in English. To be more precise, the understanding they acquire from reading analogous narratives first in their mother tongue, Chinese, might equip them with the ability to predict forthcoming text in English. This foreknowledge could lead to briefer initial fixations on words when they read in English, as they can anticipate the language more effectively. Similarly, if their first encounter is with English stories, the familiarity with the content might assist in their comprehension of the Chinese versions. Yet, the impact of starting with one's first language (L1) or second language (L2) may not be symmetrical, considering that initiating with Chinese, the L1, is typically less challenging than starting with English, the L2.To visualise the differences, five violin plots (Figure 12) were created to present how the first fixation durations of the two Chinese groups were influenced by different reading orders.

Figure 12

Violin plots of first fixation durations of two Chinese groups and the native group



In Figure 12, the y-axis represents the values of first fixation duration after power transformation. The x-axis lists both the Chinese groups in both the reading orders. “Upper CH first” refers to the first fixation durations of participants in the Upper Intermediate group who read 24 Chinese texts first, followed by the English ones. “Upper ENG first” represents the first fixation durations of participants in the Upper Intermediate group who read English first. “Advanced CH first” and “Advanced ENG first” represent the first fixation durations of the Advanced group, following the same logic. The violin plot in blue represents the first fixation durations of the English native readers.

Three main observations can be gleaned from Figure 12. Firstly, among all five groups, the mean of the first fixation duration of the native group is the lowest. Secondly, for the Upper Intermediate group, the median value of the first fixation durations was lower when they read Chinese first. This means that the first fixation durations of the Upper Intermediate group when reading English texts are on average lower if they read Chinese texts before. Thirdly, the same pattern was found for the Advanced group as the first fixation durations of the Advanced group when they had read Chinese texts first as L1 (the grey violin) was on average shorter than when they read English texts first as L2. The second and third observations tentatively suggest that reading texts in similar content in L1 first leads to shorter first fixation durations in L2.

To confirm if the reading order affected fixation times, we performed statistical tests for the two Chinese groups. Results show that for the Upper Intermediate group, those who read Chinese first had significantly different fixation times compared to those who read English first ($z = -3.5316$, $p < 0.05$). The Advanced group showed a similar significant difference in fixation times between the two reading orders ($z = -3.6955$, $p < 0.05$).

We also ran z-tests to compare the mean of the first fixation durations between the two Chinese groups in both conditions. Firstly, we did a z-test comparing the mean of the first fixation durations of the two groups when they both read Chinese first (i.e., Upper CH first and Advanced CH first). The z-value is -2.047, p-value is 0.04, meaning that when the Upper Intermediate group read Chinese texts first, their first fixation durations when reading English were statistically significantly lower than those of the Advanced group who read Chinese texts first. Besides, in the situation where both groups starting with reading English texts, there was a statistically significant difference between the two groups with $z = -3.6955$ and p is smaller than 0.05, which indicates that the mean value of the first fixation duration of the Upper Intermediate group is statistically significantly lower than that of the Advanced group.

We also did z-tests to compare the first fixation durations of both Chinese groups in both reading conditons with the native group as we use the first fixation durations results of English participants as the baseline. All z-tests comparing the first fixation durations of both groups of Chinese participants in both reading orders are statistically significantly different from the first fixation duration of the native groups. More specifically, Upper Intermediate English first vs Native, $z = 36.603$ ($p < 0.05$); Upper Intermediate Chinese first vs Native, $z = 37.167$ ($p < 0.05$); Advanced English first $z = 35.321$ ($p < 0.05$); Advanced Chinese first $z = 34.253$ ($p < 0.05$).

The above-reported results show that the differences in first fixation durations between the two Chinese groups (Upper Intermediate and Advanced) in both conditions (English first or Chinese first) and the native group are all statistically significant, and it is worthwhile to dig deeper and determine how and to what degree they differ. Table 5 illustrates the critical characteristics of the three groups' first fixation durations. Note that the original unit for mean, median and SD is milliseconds. As explained in the method chapter, all raw data were power transformed to facilitate statistical modelling and satisfy the normality assumption.

Table 5

First fixation durations of both Chinese groups in both reading orders versus the native group

Group	Mean	Median	SD	MAD
Upper CH first	6.849	6.804	0.989	0.949
Upper ENG first	6.892	6.851	0.969	0.936
Advanced CH first	6.876	6.828	0.952	0.901
Advanced ENG first	6.924	6.897	0.984	0.970
Native English	6.497	6.434	0.841	0.788

It is unsurprising that the group of native English readers had the lowest mean first fixation duration, at 6.497. This suggests that native readers took less time initially fixating their eyes on words than Chinese participants. A possible and plausible explanation for readers' differing effort in processing written language (more precisely, their first fixation duration) is their language knowledge and exposure (Mohamed, 2018). In comparison to native English readers who only know one language as monolinguals, Chinese EFL readers who are higher versus lower proficient bilinguals, inevitably have divided L1/L2 (Chinese/English) knowledge and use. Recall that all Chinese participants in this study were international students in the United Kingdom who were extensively exposed to English in their everyday life and studies. Reduced lexical availability when reading in English as a second language may explain why we observed different patterns of first fixation durations among groups and two Chinese groups with various reading orders. Reduced lexical availability is a consequence of cross-language activation, which is typical of bilinguals and entails simultaneous and nonselective activation of both Chinese and English lexical representations and decreased lexical entrenchment. This simultaneous activation results in delayed lexical access as a result of lower baseline activation levels for Chinese and English lexical representations compared to native readers (Whitford et al., 2016).

There are two interesting findings with regards to the Chinese groups. Firstly, compared to the Chinese group with more advanced English proficiency, the less advanced Chinese group had generally lower mean first fixation duration regardless of reading order. Secondly, the influence of prior experience of reading Chinese as L1 on reading English is different for both groups of Chinese participants as indicated by the values of Standard Deviation (SD). For the less advanced L2 group, reading Chinese first led to larger variance in first fixation durations when reading English. However, for the more advanced L2 group, reading Chinese first caused less variation in first fixation durations when reading English. In other words, the reading activity of reading similar content in their L1 first had a different effect on the variance in the first fixation durations of the two Chinese groups. Both groups had generally shorter first fixation durations when reading English after reading Chinese. In sum, reading order has a significant effect on the first fixation durations while reading English texts for both Chinese groups. For this reason, order of exposure is included as a variable in the statistical model that is run to predict the variance of first fixation durations, see Section 4.2.

4.2 Statistical Modelling the First Fixation Duration Data

In this section, data for the continuous variable first fixation duration (IA_FIRST_FIXATION_DURATION) were analysed using a linear mixed-effects model. Models were fitted using the lmer function from the lme4 package (Version 1.1-26, Bates, Mächler, Bolker, & Walker, 2014) in the R Environment (R Core Team, 2021) for Statistical Computing (Version 3.3.1, Rstudio Team, 2020).

We examine how different properties of a currently fixated word N, as well as different properties of the previous word (N-1) and the next word (N+1) affect the duration of the first fixations on word N. Recall that, in order to control the effect that the order of words in a text, as well as the sequence of texts in the reading experiment, may have on the duration of first fixations on word N we created a new variable called Scaled_Word_Story_Order, a variable that is a text-level property as explained in the method chapter. Furthermore, GroupAndOrder was added to the model as a participant-level variable with the difference between participants specified according to 5 levels: Native, Advanced CH first (the Advanced group who read Chinese first), Advanced ENG first (the Advanced group who read English first), Upper CH first (the Upper Intermediate group who read Chinese first), and Upper ENG first (the Upper Intermediate group who read English first).

The word properties of the currently fixated word N, of the preceding word N-1, and of the next word N+1 in the model were (scaled) Word Length, and (log-transformed and scaled) Frequency. We scaled the original values because the range of values of the data varied widely, and normalised data facilitates model fitting. For the same reason, the variable indicating word order was also scaled before we fed them to the model.

In addition to linear effects, we also examined non-linear effects using polynomials. In a basic linear correlation, the focus is on understanding how a change of one unit in a particular variable consistently affects another variable. In polynomial correlations, the focus shifts to higher-degree polynomial equations, such as quadratic (x^2), cubic (x^3), or higher-order terms. These more advanced equations allow for the exploration of complex relationships that may not be suitably captured by a linear model. Essentially, polynomial correlations are employed to determine if the relationship between variables is more accurately depicted by a curved or non-linear function, as opposed to a straightforward linear correlation. This approach is especially valuable in scenarios where linear models fail to adequately explain observed data patterns.

A complete report on the results of this model can be found in Appendix 4 on page 365.

The specification of the final best model is:

```
IA_FIRST_FIXATION_DURATION_PT ~
    GroupAndOrder /(
    Scaled_Word_Story_Order +
    poly(Wordlength_N, 3) +
    poly(Fre_log_N, 3) +
    poly(Wordlength_Prev,3)+
    Fre_log_Prev)+
    (1|Participant_ID) +
    (1|Story_ID) +
    (1|Word_ID)
```

We ran polynomial regressions to fit polynomial equations and test for possible curvilinear correlations with the goal of refining our model to produce a more accurate prediction. Polynomial regression, as opposed to simple linear regression, can be used to: 1) determine whether there is a curvilinear correlation between the independent and dependent variables; 2) determine whether the curvature is quadratic, cubic, or of other type. It thus provides the best approximation of the link between the dependent and independent variables with increased flexibility (Montgomery et al., 2012; Ostertagová, 2012). In our model, we tested polynomials on all fixed effects. Polynomials that enhanced the model's overall fit were identified and kept, based on the results of ANOVA tests.

Our analysis employs a unique approach by considering nested effects. In simpler terms, this means that certain variables are closely tied to or nested within other variables. In our study, we observed significant differences in first fixation durations among native speakers classified into three proficiency groups (Native English, Advanced, Upper Intermediate) across two reading orders. We are not just looking at the impact of word difficulty, text complexity, and individual characteristics on first fixation durations. We are also investigating how these influences vary among participants who are divided into two groups based on their language proficiency and the time they have spent in the UK.

The model included Participant_ID, Story_ID and Word_ID as random effects. We added random effects for three reasons. As mentioned in the Methodology part, there are 832 words[10] in the study. With the random effect Word_ID in the Linear Mixed-Effects Model, we can generalise our results to all English words. Secondly, we used participants' ID (EP1, EP2, EP3…; CP1, CP2, CP3….) as random effects since our focus extends beyond these specific participants to encompass the broader population of Chinese learners of English and all native English speakers. Adding Participant_ID can help us to predict the first fixation durations of the population from which the sample is drawn. Story_ID includes the topics of the stories as a random effect to be

[10] In total, the English reading stimuli include 1786 words or tokens. If repeated words are combined, there are 832 different words or types.

able to extrapolate from our experimental sample of texts and topics to all reading materials with various topics. The model's total explained variance R^2 is 0.15. This means that this model can predict 15% of variance in the first fixation durations.

Table 6 includes a complete list of variables that are statistically significant in this model to predict the first fixation durations on the currently fixated word N; these variables are discussed one by one in the next section. Visualisations are given in Figure 13 to Figure 17, to further illustrate how the three groups vary.

Table 6

A complete list of variables included in the most parsimonious model to predict the first fixation durations on word N in reading English

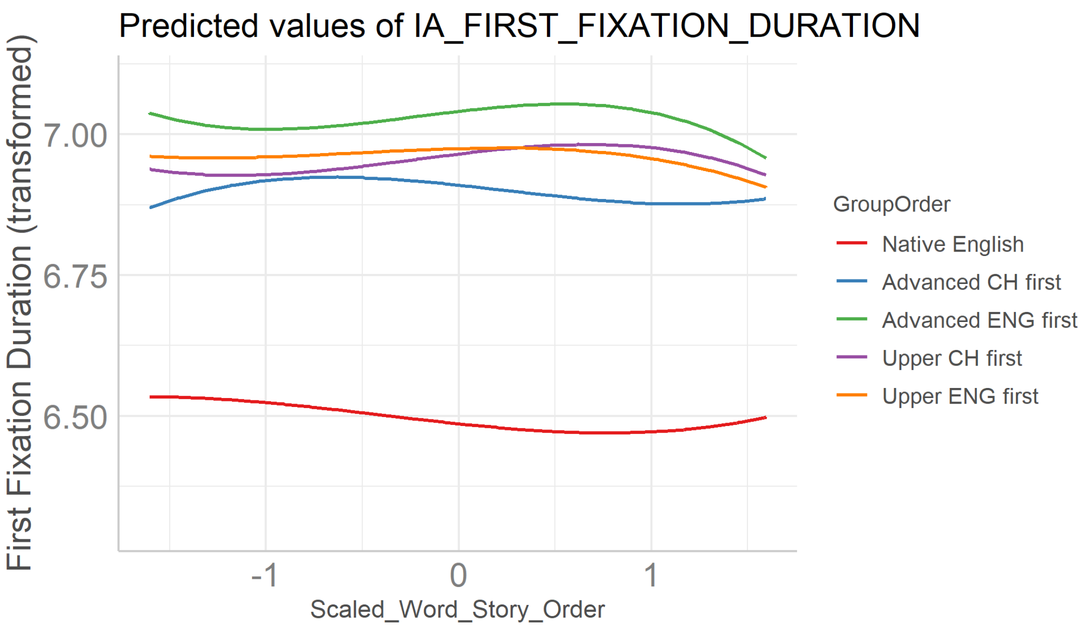
Property Types	Variable Names	Explanation
	Wordlength_N	the length of the currently fixated word N
	Fre_log_N	the frequency after logarithm of the currently fixated word N
Word-level Properties	Wordlength_Prev	the length of the word to the left of the currently fixated word. Word N-1.
	Fre_log_Prev	the frequency of the word to the left of the current fixated word, i.e., word N-1
Text-level Property	Scaled_Word_Story_Order	the combined order of a word in a story and the order of a story in the reading study

4.2.1 The Order Effect

Recall that we took the order of presenting stimuli into consideration during experiment design, as the participants might have shorter first fixation durations as they approach the end of a story and the end of the study. The variable Scaled_Word_Story_Order allows us to test how much order contributes to predicting the variance of the first fixation durations of the three groups of participants. The first fixation durations in reading English texts are shown in Figure 13 according to the model's prediction.

Figure 13

The effect of the Scaled_Word_Story_Order on the first fixation durations on word N for two Chinese groups in reading English with different reading orders compared to the native group



The x-axis depicts the scaled value of word order and story order. The greater the value, the later the word appeared in the reading study, i.e., closer to the end of a story and the end of the reading experiment. The data reveals that the native English speakers (illustrated by the red line) had consistently shorter durations of first fixations compared to the Chinese groups. Moreover, for the native group, there was a trend of decreasing first fixation durations as they progressed through the texts and words, suggesting they read more quickly over time. Essentially, as the native participants advanced to the later parts of a story and through the series of 24 stories, the time they spent on the first fixation of each word tended to reduce.

Among the three groups, only the native group and the Advanced group who read English first demonstrated a statistically significant relationship between word story order and first fixation durations on word N. The interaction effect of scaled_word_story_order on GroupOrder [Native] is statistically significant and negative (Estimates value = -5.61, $p < 0.001$).

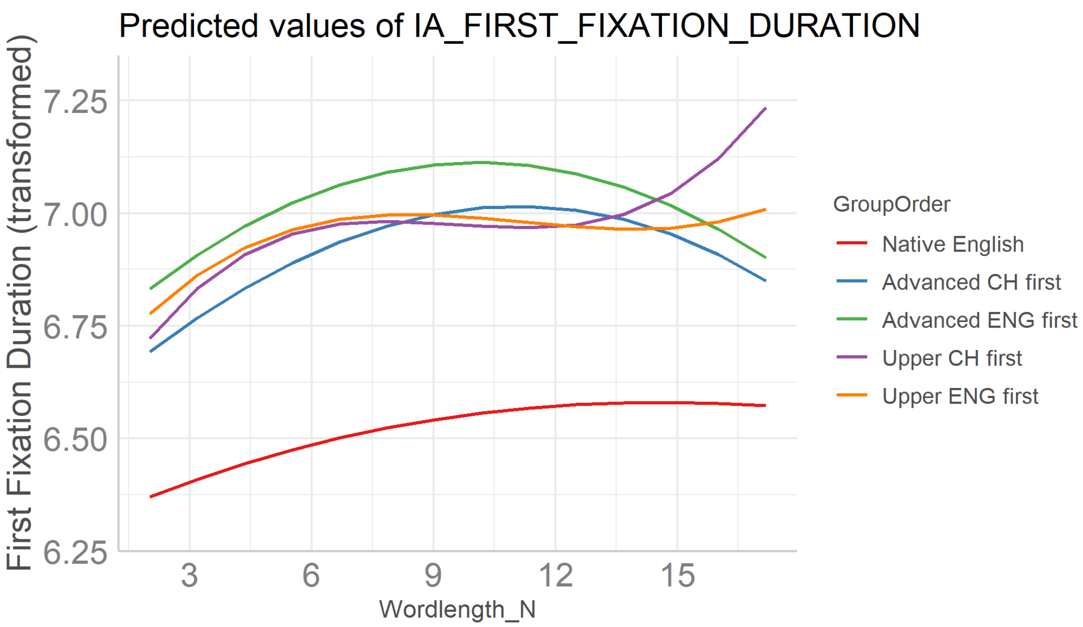
We also found a statistically significant relationship between the first fixation durations of the Chinese Advanced group who read English first and the Scaled_Word_Story_Order; the Estimate value is -0.496, and the p-value is 0.02. This suggests that for the Advanced group, the duration of the first fixation while reading in English was influenced by the location of words within the story and the sequence of texts in the experiment, but only if they started with English texts.

4.2.2 The Effect of the Length of Word N

Figure 14 displays the time spent on the first fixation when reading English, as per the models. We looked into how this time varies for the two Chinese participant groups based on their reading sequence, and for the native English speakers.

Figure 14

The effect of the length of the currently fixated word N on the first fixation durations on word N for two Chinese groups with different reading orders compared to the native group



The x-axis represents the length (number of letters) of the currently fixated word ranging, from 1 to 16. The y-axis represents the first fixation durations (with a range from 6.3 to 7.3).

For all groups, the durations of the first fixation increase as the number of letters in the words increases: the longer a word is, the longer the first fixation duration on it will be. The first fixation durations of the Advanced and Upper Intermediate in both reading orders are significantly longer than those of the native group, meaning that L2 readers take longer than native speakers when they fixate their eyes on a word for the first time.

Noteworthy is the evident distinction between the two Chinese groups in both reading orders. The Advanced group who read Chinese first (the blue line) has the shortest first fixation durations and their first fixation durations were higher if they read English first. Comparatively speaking, the Upper Intermediate group had longer first fixation durations (as indicated by the orange and purple lines). In other words, by comparing their first fixation durations, it is possible to see that Advanced (who had a higher level of L2 language proficiency and more exposure) was quicker than Upper Intermediate at English word recognition.

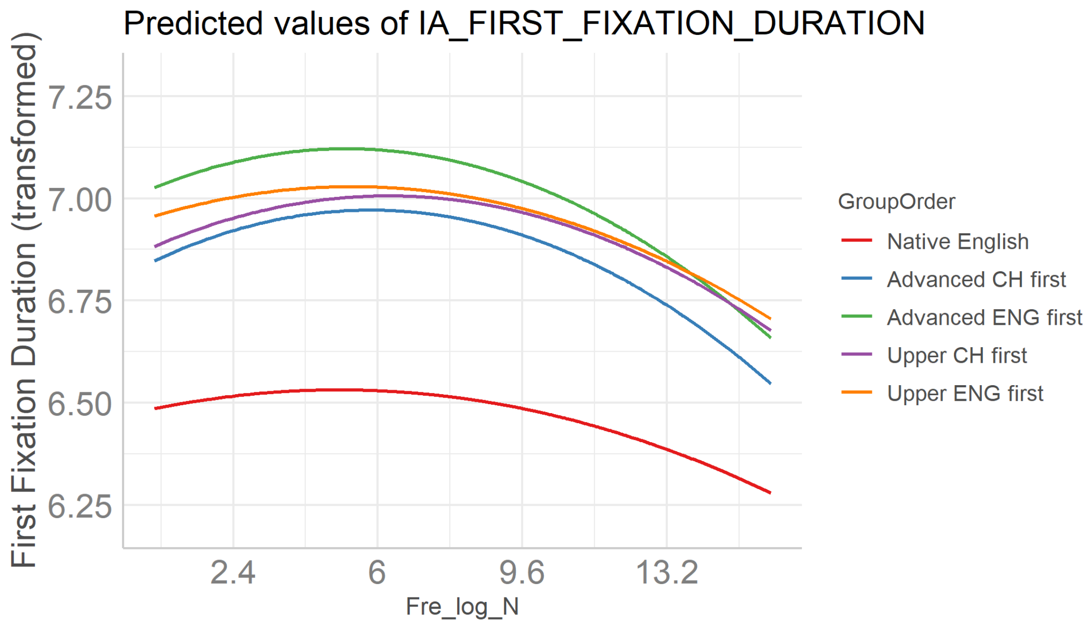
However, as per the effect of length of word N on first fixation durations, we can observe a distinction between the Advanced group and the Upper Intermediate group. In Figure 14 the pattern of the Advanced group begins to resemble that of natives (see the similarity between the pattern of the blue and green line and the red line). For Upper Intermediate the (orange and purple) lines continue to increase while for Advanced, the blue line and the green line drop after the length of word N is close to nine letters. The continued increasing trend for the Upper Intermediate shows that the Upper Intermediate group struggled even more with longer words than the Advanced group. Put simply, longer words with more letters tend to be more challenging for Chinese participants with less proficiency and exposure in the English.

4.2.3 The Effect of the Frequency of Word N

The first fixation durations when reading English texts are shown in Figure 15 according to the model's predictions based on the word frequency of the currently fixated word N.

Figure 15

The effect of the frequency of the currently fixated word N on the first fixation durations on word N for two Chinese groups with different reading orders compared to the native group



The x-axis shows word frequency (after power transformation) of the currently fixated word. The y-axis represents the first fixation durations.

The plot in Figure 15 illustrates how the durations of the three groups' first fixation durations change as the frequency of the fixated word increases. A similar pattern can be observed across all groups and conditions: the more frequent the words in the British National Corpus (BNC), the shorter the duration of the first fixations. This suggests that frequent words are processed more quickly by both L1 and L2 readers, likely due to their greater familiarity with these words and the related ease with which they are retrieved from memory.

The interaction between word frequency and first fixation duration aligns with broader linguistic findings regarding word length. In most cases, there is a strong relationship between the length and frequency of words across various text corpora.

Kliegl et al. (2004) reported that shorter words are typically encountered more frequently. In this study, the Pearson's product-moment correlation reinforces this understanding; the frequency of the words and their word length is negatively correlated, and the effect that is statistically significant and very large ($r = -0.68$, 95% CI [-0.70, -0.66], $t(1782) = -39.23$, $p < 0.001$). This negative correlation indicates that longer words are less frequent and hence require more cognitive effort to process, as reflected in longer fixation times. Conversely, the shorter and more frequent words likely contribute to the decreased gaze durations noted earlier, as they are more readily accessed and recognised by the reader, regardless of their language proficiency level.

4.2.4 The Effects of the Previous Word N-1

The influence of the preceding word (N-1) on the currently fixated word (N) has been extensively studied and documented in the literature on eye movements during reading in English. Previous research has specifically examined the phenomenon, often referred to as the "spill-over effect," which highlights the carry-over impact of the preceding word on the processing of the current word. Several studies have investigated how properties of the previous word, such as its length, frequency, or predictability, can influence first fixation durations on the current word. The spill-over effect is summarised by Brunfaut and McCray (2015) that processing of word N-1 may influence the duration of the fixation on word N if the eyes moved from word N-1 to word N before lexical processing of word N-1 was finished.

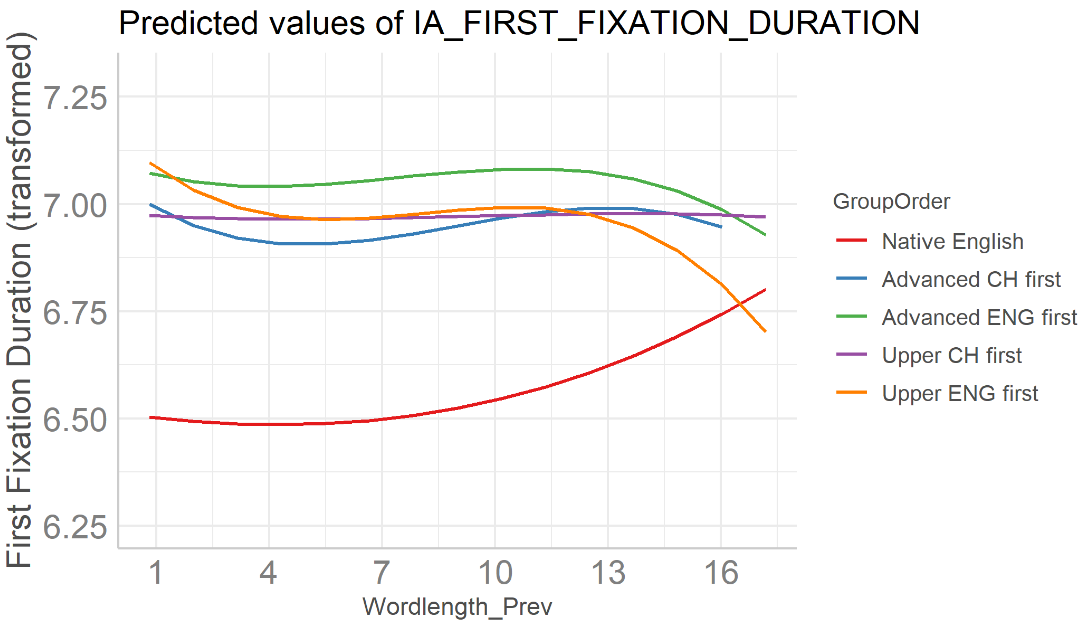
This preview benefit is commonly interpreted as an indication for pre-processing a neighbouring word N+1 during fixations on word N and for integrating parafoveal information across saccades to help the subsequent foveal processing. The parafoveal preview of the upcoming words should benefit general reading. Incomplete processing of the preceding word is typical for words with low frequency, thereby causing longer fixation durations on the currently fixated word (Engbert et al., 2005).

On average, a fixation on a long word N-1 will be further away from word N, reducing the preview benefit for word N caused by the loss of visual acuity associated with that distance. As a result, the length of word N-1 predicts the duration of the fixation on word N. Therefore, we expect to see in our data a positive relationship between the length of word N-1 and the first fixation durations on word N, because a longer word N-1 places the current word N further away from the centre of word N-1, resulting in a diminished preview effect. In other words, the longer the word N-1 is, the longer the first fixation duration on the word N will be, as the word N-1 provides less preview benefit.

The effect of the length of the word N-1. The plot in Figure 16 displays the correlations between the preceding word's word length (the original values were scaled) and the first fixation durations (power-transformed).

Figure 16

The effect of the length of the previous word N-1 on the first fixation durations on word N for two Chinese groups with different reading orders compared to the native group



The x-axis depicts the word length of the preceding word N-1 after scaling; the y-axis exhibits the first fixation durations after power transformation.

Let us zoom in and examine the similarity and variation in the plot regarding the word length of the preceding word N-1 and their influence on the first fixation durations on the currently fixated word N. The line showing the change of the first fixation duration of the native group (in red) exhibits a smooth and consistent upward trend as soon as the scaled word length of the preceding words exceeds 8 letters, after remaining stable between 1 letter and 7 letters. Note that it is found statistically significant according to the model. The findings indicate that the length of the preceding word (N-1) had a significant influence on the duration of the first fixation, specifically among native readers as L1 readers. This implies that native readers are more sensitive to the length of the preceding word when it exceeds a certain threshold.

The correlation between Wordlength_Prev and the (power transformed) first fixation durations for Advanced and Upper Intermediate learners shows different trends with the native group. For the Advanced group (the blue line and green line), we can see a declining trend as the length of the previous word ranges from 2 to 5 letters, regardless of reading order. When the length of the previous word exceeds 14 letters, a negative correlation was observed between word length and first fixation durations in the Advanced group. In other words, as the length of the previous word increased beyond the 14-letter threshold, the duration of their initial fixations on the currently fixated word tended to decrease. This negative correlation implies that when advanced readers encountered exceptionally long preceding words, they exhibited a tendency to allocate less time for processing the currently fixated word. These results indicate that advanced readers may adopt different reading strategies or employ more efficient cognitive processing mechanisms. When confronted with excessively long preceding words, they may rely on their advanced reading skills to quickly extract information and allocate fewer fixations on the currently fixated word. The negative correlation highlights the intricate interplay between word length, reading proficiency, and strategic allocation of attention during the reading process.

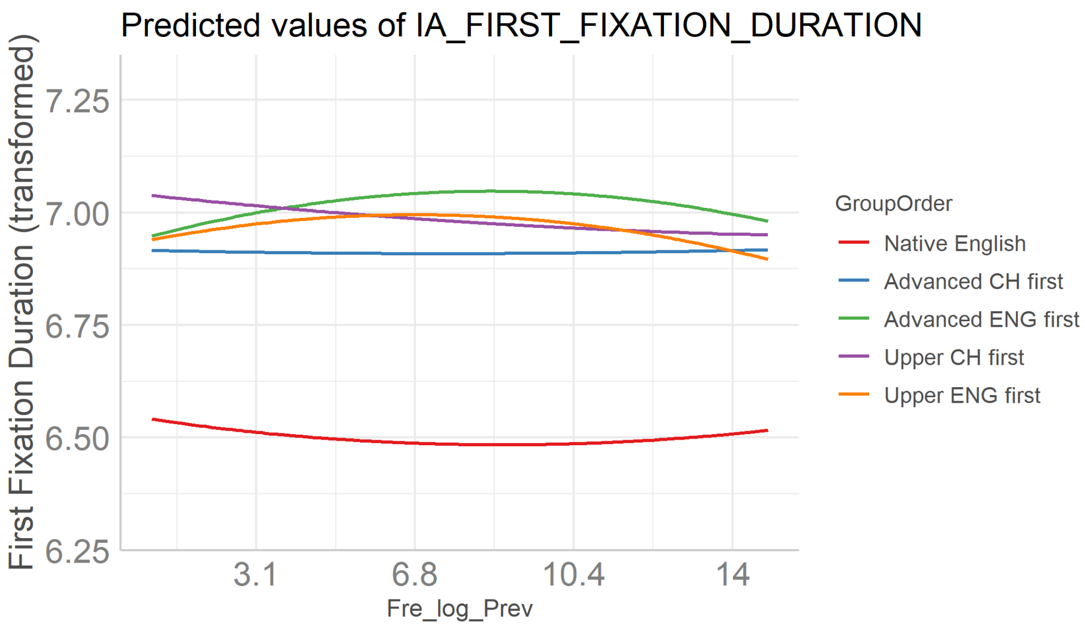
A very interesting difference can be observed for the Upper Intermediate group in two reading orders. When the Upper Intermediate group read Chinese texts first (the purple line in Figure 16), there is no correlation between the word length of the preceding word N-1 and the first fixation duration on word N. However, as the orange line presents, if participants in the Upper Intermediate group read English texts first, we observe a statistically significant negative relationship between the length of the previous word N-1 and the first fixation duration on the currently fixated word N, meaning that as the length of the previous word increases, the first fixation durations of the Upper Intermediate group who read English first declined.

In conclusion, in our data, we see a spill-over effect caused by the length of the previous word on the first fixation duration of the current fixated word in native readers' eye-movement patterns, yet no clear spill-over effect can be found in either of the Chinese groups.

The effect of the frequency of word N-1 In this section, we present and plot the modelling results regarding the relationships between the frequency of the previous word, and the first fixation durations in Figure 17.

Figure 17

The effect of the frequency of the previous word N-1 on the first fixation durations on word N for two Chinese groups with different reading orders compared to the native group



The x-axis depicts the word frequency of the preceding word N-1 after scaling; the y-axis represents the first fixation durations after power transformation.

We added the frequency of the previous word as a fixed effect in the model to test the possible impact of the properties of word N-1 on word N. What we can observe is that, again, the first fixation durations of the native group (as indicated by the red line) are the lowest. According to the modelling results (for full details see Appendix 4 on page 365), the relationship between the first fixation durations of the native group and the frequency of the previous word is statistically significant and the Estimates value is -4.093, p-value is 0.027. This implies that more commonly occurring words that come before tend to be associated with shorter first fixation durations on the following word. This could indicate that familiar words help to prime the reader for what comes next, enabling quicker processing and understanding.

For the Upper Intermediate group, a significant relationship between the frequency of the previous word and the first fixation duration on the current word was observed, but this was only when they read the English texts before the Chinese ones. The estimate for this effect is -7.993 with a p-value of 0.028 at the linear level, indicating a strong inverse relationship—higher frequency of the preceding word tends to shorten the first fixation duration on the current word. Additionally, there is a significant quadratic relationship with an estimate of -0.691 and a p-value of 0.011, suggesting that the effect of word frequency on fixation duration might change at different frequencies of the preceding word.

For the Advanced group, a significant effect was also seen, but again only when they read English texts first. The significant relationship here is represented at the quadratic level with an estimate of -7.581 and a p-value of 0.003. This indicates a complex relationship where the influence of the preceding word's frequency on the first fixation duration is not a straight line but rather varies depending on the frequency level of the preceding word.

Chapter 5: The English Reading Study - Gaze Duration

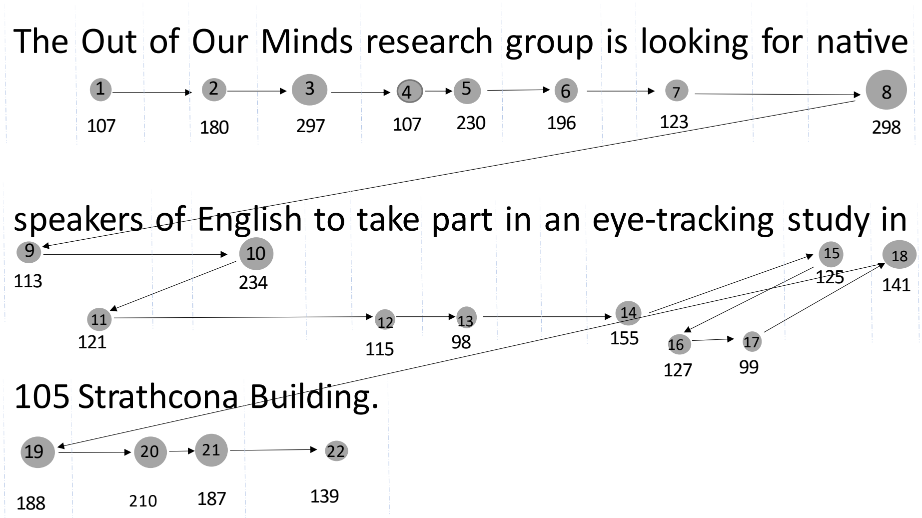
Words are sometimes fixated more than once, which means that the first fixation duration might not capture the full extent of overall fixation time. In this chapter, our attention shifts to another common metric for instances when a word attracts multiple fixations: gaze duration. Gaze duration, sometimes referred to as first pass reading time or first run dwell time, encompasses the total time of all fixations on a region before the eyes move away from that region, be it to the left or right of the word in question.

Given the importance of foveal vision in reading, it will not be surprising that word length also has a significant effect on gaze durations. Typically, gaze duration on long words is longer than that on short words. Increases in word length are associated with increments in gaze duration (Calvo & Meseguer, 2002). Besides word length, word frequency also plays an important role in predicting gaze durations (Pollatsek et al., 2006). It has been reported that the gaze durations on words with high frequency are shorter than those with low frequency.

Here we offer an example of how we define gaze duration in this study. In the hypothetical eye-movements example in Figure 18 the gaze duration for the word ‘research’ is the total of fixations 4+5, and the gaze duration for the word ‘Strathcona’ is the total of fixations of 20+21.

Figure 18

Hypothetical eye-movements (fixations and saccades) during silent reading



Note. Each word is regarded as an Interest Area (IA) with a dashed line separating them for the purpose of presentation. Grey circles indicate fixations and arrows show saccades with various directions and lengths. Numbers (1-22) in circles show the order of fixations. Fixations are given in milliseconds below the word on which they occurred for the purpose of presentation.

Words can be fixated more than once for different reasons. When words are visually long in a text, some letters are out of the reader's foveal area which makes it hard to see them clearly, so readers make intra-word saccades because of acuity limitations. That is, readers may make a saccade to the next part in the same word they want to read. A few low-level oculomotor factors such as word length are possible explanations for refixations on a word: longer words lead to increasing number of fixations, consequently, longer gaze durations.

However, little is known about how the reading patterns of L2 readers with different language proficiency levels and exposure are different from native speakers. Gaze duration is normally reported as an important measure of processing effort

(Engbert et al., 2002). It means that if the gaze durations are long, the words cause more processing effort to readers. However, readers with different proficiency levels also behave differently and show various eye-movement patterns in reading, such as various length of time spent on word recognition. In this chapter, we will explore how and to what extent readers with various proficiencies show different gaze durations during L2 reading.

As in Chapter 4 on first fixation durations in reading English, we will start with preliminary data analysis before moving to statistical modelling. The two main questions this chapter will address are as follows:

1. Are there differences in gaze durations when reading English between the two Chinese groups and the native group?

2. Can L2 proficiency and exposure be used as an indicator to explain different patterns of gaze duration of Chinese participants as L2 readers?

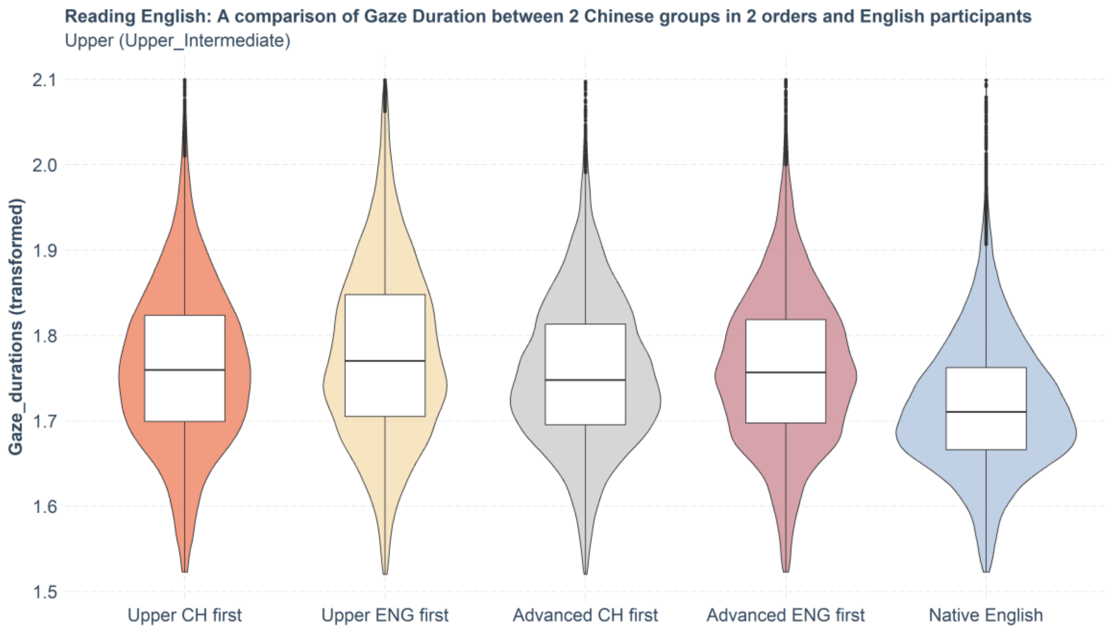
5.1 Preliminary Data Analysis

The question we are trying to answer in this section is how Chinese participants' gaze durations in the English reading task are influenced by their language proficiency and exposure, while controlling for the order in which they read the texts. Recall that, in this study, Chinese participants read both Chinese and English stories, which were either similar or identical. They saw these in different orders: 19 of them were assigned to read Chinese texts first and 20 to read English texts first. When reading Chinese stories first, it is likely that Chinese readers gained a general impression of the text. Because of this, when reading on the same topic in L2, their reading behaviour, especially their eye-movement measures might be affected. More specifically, they will have gained an impression of the content, and may have remembered the general idea, which may have enabled them to anticipate the upcoming words or syntactic meaning of the upcoming phrases and their gaze duration on the words in their L2 may have been shortened because of this. In the same vein, if they read English stories first, their impression of the content could also contribute to their processing of the stories in Chinese when they noticed the familiar content in L1. However, the influence of reading texts in L1 or L2 could be different as reading in Chinese as L1 first is easier than reading in English as L2. Therefore, the order of experimental texts needs to be considered when examining the gaze durations of Chinese participants.

In Figure 19, we present the distributions of gaze durations for both Chinese participant groups across the two reading orders, along with the gaze durations of native speakers. The leftmost pair of violin plots represents the gaze durations of the Upper Intermediate group. Notably, we observe that in the English reading study, when the Upper Intermediate group read Chinese first, their median gaze duration is shorter compared to when they read English first. This implies that, on average, the Upper Intermediate group exhibits shorter mean gaze durations when reading English second. A similar trend can be observed for the Advanced group. However, it is important to highlight that the gaze durations of the native speaker group consistently recorded the shortest durations among the five groups.

Figure 19

Violin plots of gaze durations of two Chinese groups and the native group



We list key features of the gaze durations recorded while the Chinese participants read English in Table 7. English participants' gaze durations are added as a baseline to compare. Note that the gaze duration values are all power transformed.

Table 7

Gaze durations of both Chinese groups in both reading orders versus the native group

Groups	Mean	Median	SD	MAD
Upper CH first	1.763	1.759	0.094	0.092
Upper ENG first	1.778	1.770	0.103	0.104
Advanced CH first	1.755	1.748	0.087	0.085
Advanced ENG first	1.760	1.756	0.090	0.090
Native English	1.717	1.710	0.078	0.071

Some interesting results can be found here in Table 7 which offers some key features regarding the gaze duration of two Chinese groups in two conditions and English participants. Firstly, both Chinese groups' mean value of gaze durations in reading English were statistically significantly lower if they read Chinese texts first. For the Upper Intermediate group, the mean value of gaze durations in reading English is 1.763 when they read Chinese first, and the mean is 1.778 when they read English first. A z-test was run to test whether the difference is statistically significant. As the result shows, $z = -12.338$, $p < 2.2e-16$, which shows that the difference between the two mean values of gaze durations of the Intermediate group is statistically significant. Put differently, reading Chinese texts with similar content first helped the Upper Intermediate group when reading English, shown by statistically shorter mean value of gaze durations in reading English. The same results can be found for the gaze durations of the Advanced group. The mean gaze duration of the Advanced group in reading English with prior experience of reading Chinese texts is 1.755, while the mean in the condition without reading Chinese texts previously is 1.76. A z-test was run to compare the means of the two conditions for the Advanced group ($z = -4.0393$, $p < 0.05$). The result indicates that the difference of gaze durations between those who read Chinese first and who read English first is statistically significant. The second finding relates to the standard deviation (SD). Both groups showed a smaller SD of the gaze durations if they read Chinese first. More specifically, for the Upper Intermediate group, the SD of gaze durations when they had read Chinese texts first is 0.094, while the SD of gaze durations when reading English first is 0.103. For the Advanced group, the SD of gaze duration when read Chinese first is 0.087, while the SD in the other condition is 0.09.

It is worthwhile to compare our findings on gaze duration to those on first fixation durations in reading English. In terms of first fixation durations, we found a statistically significant effect of prior experience of reading Chinese texts with similar content for both the Upper Intermediate group and the Advanced group. Here, with regards to gaze durations in reading English texts, similarly, both groups demonstrated a significant difference in gaze durations in reading English, more precisely, we observed shorter gaze durations in reading English on the currently fixated word, if they had read Chinese first.

5.2 Statistical Modelling the Gaze Duration Data

In this section, data for the continuous variable gaze duration (IA_GAZE_DURATION) were analysed using a linear mixed-effects model. This model was fitted using the lmer function from the lme4 package (Version 1.1-26) in the R Environment for Statistical Computing (Version 3.3.1).

Recall that gaze duration is the sum of all fixations on a word before the reader moves their eyes away from the word. We will examine different properties of what affects gaze duration. The first type includes properties at the word-level. We begin with properties of the currently fixated word (word N) by taking its length and frequency into account. Furthermore, the properties of the neighbouring words, the previous word N-1, and the next word N+1, were also added into the model to test their possible influences on the gaze durations of the currently fixated word N.

Instead of directly fitting a model to the original data, we scaled the values of all properties at word level facilitate model fitting. For the same reason, we scaled the value of Word_Story_Order into Scaled_Word_Story_Order.

Table 8

A complete list of variables included in the most parsimonious model to predict the gaze durations on word N in reading English

Property Types	**Variable Names**	**Explanation**
	Wordlength_N	the length of the current fixated word N
	Fre_log_N	the word frequency after logarithm of the current fixated word N
Word-level Properties	Wordlength_Prev	the length of the word to the left of the current fixated word, i.e., word N-1.
	Wordlength_Next	the length of the upcoming word, N+1
	Fre_log_Prev	the frequency of the word to the left of the current fixated word, i.e., word N-1
	Fre_log_Next	the frequency of the upcoming word, N+1
Text-level Property	Scaled_Word_Story_Order	the combined order of a word in a story and the order of a story in the reading study

Our analysis employs a unique approach by considering nested effects. In simpler terms, this means that certain variables are closely tied to or nested within other variables. In our study, we observed significant differences in gaze durations among participants classified into three proficiency groups (Native English, Advanced, Upper Intermediate) across two reading orders. We are not just looking at the impact of word difficulty, text complexity, and individual characteristics on gaze durations. We are also investigating how these influences vary among participants who are divided into two groups based on their language proficiency and the time they have spent in the UK.

The specification of the final best model is:

```
IA_GAZE_DURATION_PT~
    CEFRGroups/(
    poly(Scaled_Word_Story_Order,3) +
    poly(Wordlength_N, 3) +
    poly(Fre_log_N, 3) +
    poly(Wordlength_Prev,3)+
    poly(Wordlength_Next,3)+
    poly(Fre_log_Prev,3)+
    poly(Fre_log_Next,3))+
    (1|Participant_ID) +
    (1|Story_ID) +
    (1|Word_ID)
```

Note that in this model we set the gaze durations of the native English readers as baseline by using the relevel function in R. The model has a total explanatory power of 0.3, which implies that it can predict 30% of the variance in gaze duration.

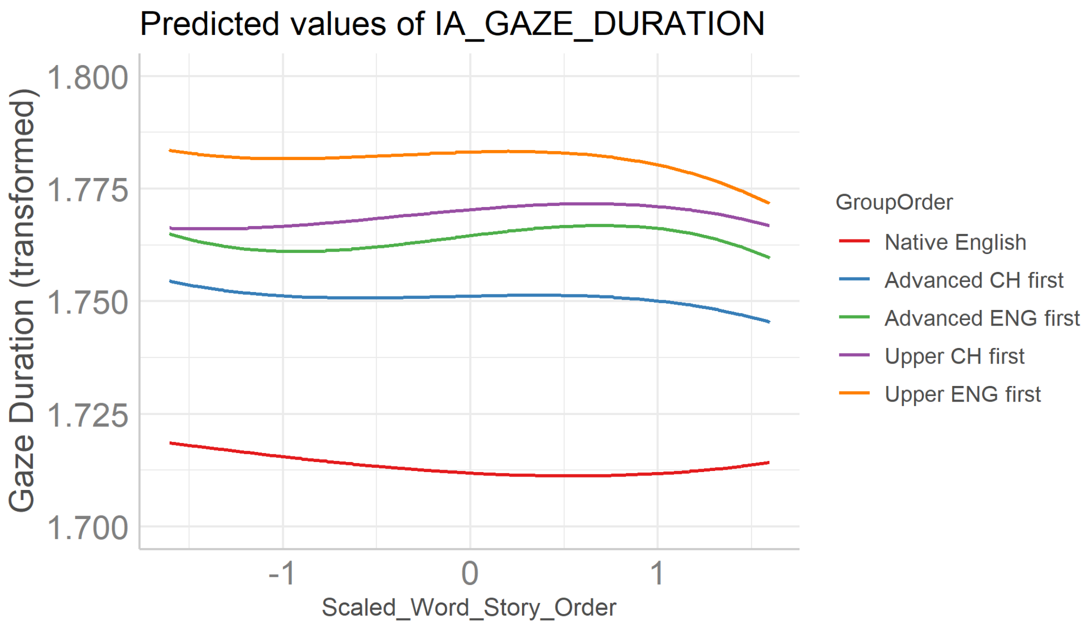
The next section presents a description of all fixed effects in the model for predicting gaze durations that are statistically significant, as determined by the test statistic. We have visualised the results, which are presented separately, to demonstrate how these correlations differ across language levels and reading orders.

5.2.1 The Order Effect

The power transformed and scaled gaze durations in reading English texts are shown in Figure 20 according to the model predictions of the scaled order of the currently fixated word. More specifically, we examined how these relationships are different for both groups of Chinese participants in both reading orders versus the native group.

Figure 20

The effect of the Scaled_Word_Story_Order on the gaze fixations on word N for two Chinese groups in reading English with different reading orders compared to the native group



The x-axis depicts the scaled value of the word order and story order. The range of values on the x-axis ranges from -1.6 to 1.6 (after scaling), and the range of the values on the y-axis is from 1.7 to 1.8 (after power transformation). On the x-axis, the greater the value is, the later the word appeared in the reading study, i.e., the higher the value, the closer the word is to the end of a story and the story to the end of the reading experiment.

The pattern of English participants as native speakers is shown by the red line, the pattern of the Advanced group who read Chinese texts first is represented by the blue line and those who read English texts first is shown in green. The pattern of Upper Intermediate who read Chinese texts first is the purple line, and the orange line represents the Upper Intermediate group who read English texts first.

As indicated in Figure 20, the native group showed shorter gaze durations than the two Chinese participant groups in both reading orders. Additionally, the native group had shorter gaze durations across trials. In simpler terms, the trend observed is that as English participants read more texts and encountered more words, their gaze durations decreased: as they progressed towards the conclusion of a story and eventually completed all 24 stories, they became more efficient at decoding words, resulting in shorter gaze durations.

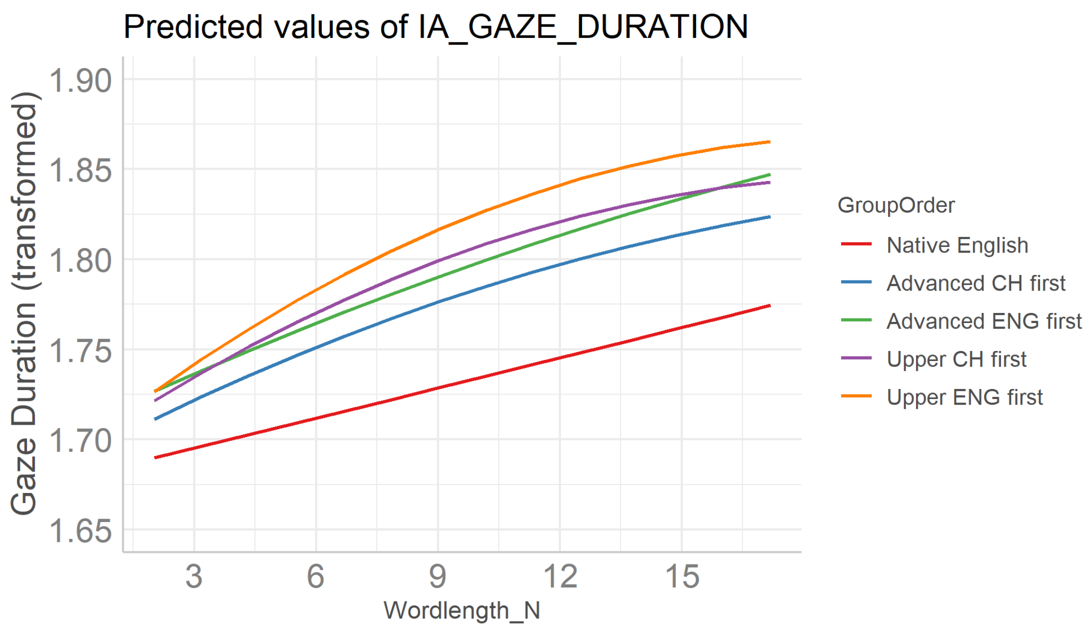
A statistically significant linear negative correlation can be found in the native group, with the Estimates value as -0.47 ($p < 0.001$). This means that, at the linear level, as the Scaled_Word_Story_Order increases one unit, the gaze durations decrease 0.47. For both Chinese groups, the only statistically significant linear relationships were found between the Scaled_Word_Story_Order and the gaze durations on the currently fixated word. More specifically, at the linear level, we found a positive relationship (Estimate coefficient = 0.377, $p = 0.043$) between the word order and the gaze durations on word N if the Upper Intermediate group read Chinese first. However, a negative relationship (the Estimate coefficient is -0.553, $p = 0.006$) was found if the Upper Intermediate group read English texts first. In the Advanced group, a negative non-linear regression was observed, indicating a curvilinear association, between Scaled_Word_Story_Order and gaze durations when participants read English first (the Estimated coefficient is -0.52, $p = 0.006$). The negative non-linear effect suggests that, as the Scaled_Word_Story_Order increased, gaze durations tended to decrease among participants in the Advanced group who read English first, as was the case for native readers. This implies that, as participants progressed further into the story or encountered words later in the narrative, their gaze durations on those words decreased.

5.2.2 The Effect of the Length of Word N

The power-transformed and scaled gaze durations in reading English texts are shown in Figure 21 according to the model predictions of the word length of the currently fixated word. More specifically, we examined how these relationships are different for the two groups of Chinese participants in both reading orders versus the native group.

Figure 21

The effect of the length of the currently fixated word N on the gaze durations on word N for two Chinese groups with different reading orders compared to the native group



The x-axis captures word length, indicating the length (number of letters) of the currently fixated word. The y-axis depicts gaze durations.

The plot in Figure 21 shows the relationship between the length of the currently fixated word and gaze durations for three groups and two reading orders. Before we analyse different relationships and compare patterns of the native group, the Advanced group and the Upper Intermediate group across various reading orders, it is necessary to find how statistically significant these relationships are in the model. A full list of results can be found in Appendix 5 on page 369. Note that if the predictor is affixed with 1, the relation is linear; if the Predictor is affixed with 2, the relationship is quadratic; if 3, cubic. More specially, the Estimates indicate that the regression coefficient for the Advanced group reading Chinese first is 0.038 ($p < 0.001$), for the Advanced group reading English first is 0.047 ($p < 0.001$), for the Upper Intermediate group reading Chinese first is 0.047 ($p < 0.001$), and for the Upper Intermediate group reading English first is 0.051 ($p < 0.001$). These positive coefficients indicate that for all three groups, as the word length of the currently fixated word increases with one unit, the gaze duration on this word will increase 1) 0.038 for the Advanced group who read Chinese first; 2) 0.047 for the Advance group who read English first; 3) 0.051 for the Upper Intermediate group who read Chinese first; 4) 0.066 for the Upper Intermediate group who read English first.

As per the linear relationships between word length of the currently fixated word and gaze durations, statistically significant relations can be found in all groups and in both orders. More specifically, the Estimate values of the native group is 4.728, the Advanced group who read Chinese first is 7.261, who read English first is 7.351, and Upper Intermediate group who read Chinese first is 8.396 and who read English first is 9.699, and the p-values are all statistically significant. What is more, the effect of the length of the currently fixated word N had a stronger influence on the Upper Intermediate group than on the Advanced group and had the smallest influence on the native English group as the Estimates value of the native group is the lowest (4.728). This suggests that the native group placed the least reliance on low-level word properties, such as word length, when it came to their gaze durations.

Native L1 readers generally have more exposure to English, while the Advanced group and the Upper Intermediate group who are Chinese have reduced L2 reading exposure compared to their respective L1 (Chinese) exposure. Consequently, native readers showed shorter gaze durations when reading English as they needed less time to finish early-stage lexical processing (i.e., word recognition) and less times to re-fixate a word before they moved their eyes out of the current word and to the upcoming word.

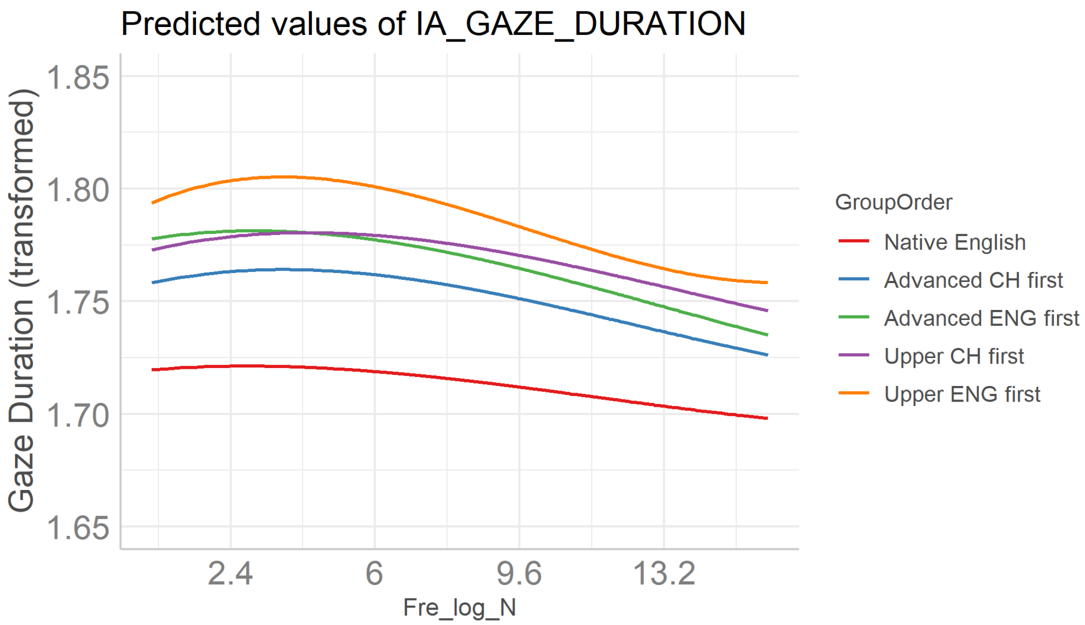
However, the two Chinese groups, the Advanced group and the Upper Intermediate group, as bilingual readers, had generally longer gaze durations because of cross-language activation (i.e. simultaneous and nonselective activation of both L1 and L2 lexical representation) and reduced lexical entrenchment (i.e., delayed lexical access resulting from reduced L1 and L2 baseline activation levels and/or weakened L1 and L2 lexical memory representations) (Whitford et al., 2016). The Advanced group and the Upper Intermediate group differ among themselves in terms of gaze durations as the Advanced group had a generally shorter gaze duration than the Upper Intermediate group. It is interesting to find that L2 readers with different L2 language proficiencies showed distinct gaze durations. In other words, it is possible to use the eye-movement measure (gaze duration) and its patterns to distinguish L2 readers with different language proficiencies as well as the durations of staying in the UK and their language processing skills.

5.2.3 The Effect of the Frequency of Word N

The plot in Figure 22 shows the relationships between the frequency of the currently fixated word and gaze durations for the three groups of participants.

Figure 22

The effect of the frequency of the currently fixated word N on the gaze durations on word N for two Chinese groups with different reading orders compared to the native group



We observe that, as the frequency of the currently fixated word increases, the gaze durations of all three groups decline. However, we can zoom in on and compare the differences between groups based on the relationships between frequency and gaze durations. When it comes to the linear correlations, the coefficient values of all three groups are negative and statistically significant ($p < 0.001$): as words become more frequent, the gaze durations on that word become shorter. Nonetheless, the coefficient values vary significantly between groups. Native has a coefficient value of -1.801, which implies that when the frequency of the currently fixated word increases by one unit, the duration of the gaze on it decreases by 1.801. However, for the Advanced group, increasing the frequency of the currently fixated word by one unit resulted in a higher drop of -2.897 when they read Chinese first, and a drop of -3.528 if they read English first. For the Upper Intermediate group, the Estimates value is -2.53 when they read Chinese first, but we see a larger drop of 3.753 drop if they read English first.

The linear effects of this variable on the three groups indicate that the frequency of the currently fixated word had the greatest effect on the gaze durations of the Upper Intermediate group who read English first, then the Upper Intermediate group who read Chinese first. The same pattern can be found in the Advanced group as the influence of the frequency of the currently fixated word is greater if they read English first. To summarise, the gaze durations of the two Chinese groups showed a smaller influence of frequency of the currently fixated word in reading English if they read Chinese first.

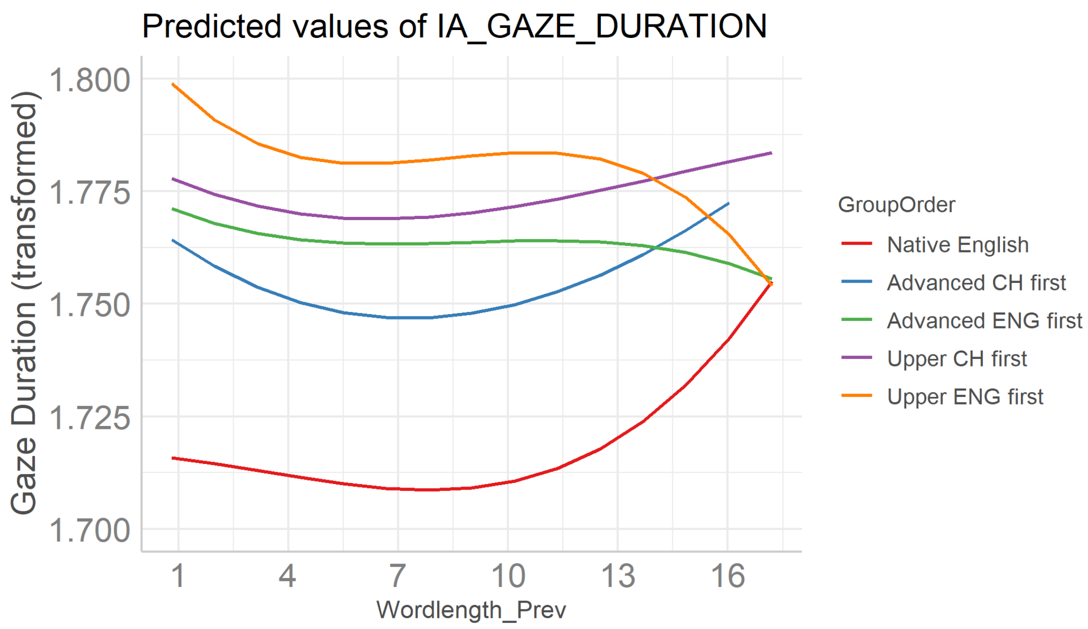
5.2.4 The Effects of the Previous Word N-1

As previously stated, the word length of word N-1 (Wordlength Prev) and the word frequency of word N-1 (Fre_log_Prev) were also added as fixed effects to predict the currently fixated word's gaze durations. Recall that while our eyes are fixed on a word, the spatial extent of visual processing (the perceptual span) during a fixation extends significantly beyond the fixated word, reaching no more than four letters to the left and fourteen to fifteen letters to the right of the currently fixated word in alphabetic languages (Ming Yan et al., 2012; M. Yan et al., 2012). As the results of the model for gaze durations indicate, two properties of the previous word N-1 had significant effect on the gaze duration of the currently fixated word, length, and frequency. We will now present more detailed results about how the length and frequency of word N-1 influence gaze durations on word N in reading English.

Figure 23 illustrates the relationship between the word length of N-1 and gaze durations on the currently fixated word N. The x-axis depicts the length of the preceding word N-1. With the help of the plot, it is possible for us to know the general relationships between the length of word N-1 and gaze durations on word N.

Figure 23

The effect of the length of the previous word N-1 on the gaze durations on word N for two Chinese groups with different reading orders compared to the native group



The plot in Figure 23 reveals obvious difference between the two Chinese groups in both reading orders, and differences with the native group. When the Upper Intermediate group read English first (the orange line), there is a negative relation between the length of the previous word and the gaze durations on the currently fixated word, which means that as the length of the previous word increases, the gaze durations on the currently fixated word N increase. However, for participants in the Upper Intermediate group who read Chinese first (the purple line), there is a positive relationship as the word length of the previous word exceeds 7 letters meaning that gaze duration on that word increases. A similar pattern can be observed for the Advanced group who read English first (in green), yet the pattern of the Advanced group who read

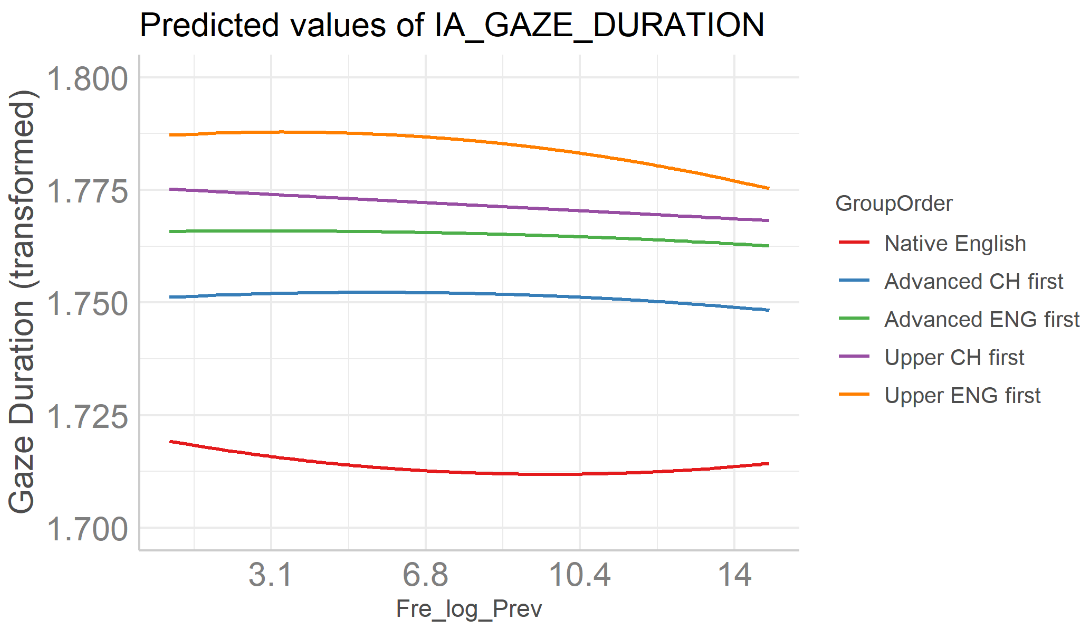
Chinese first is very similar to the native group. There is a noticeable difference between the Upper Intermediate group which read English first (the orange line), and the behaviour exhibited by the native English group (the red line). The English group (red line) exhibits a consistent, almost linear decline in gaze duration as word length increases. The Advanced Chinese first group (orange line) shows an initial decline in gaze duration but starts increasing after a Wordlength_Prev value of around 7. This contrast becomes pronounced when the previous word's length exceeds seven letters, causing a significant divergence between the two lines.

According to the model results of the model in Appendix 5 on page 369, at the linear level, both Chinese groups had a statistically significant negative relationships in both reading orders: as the length of the previous word increases, the gaze durations on the currently fixated word N increase. The Advanced group who read Chinese first have a coefficient value of -1.325 ($p < 0.001$), which means that as the word length of the preceding word N-1 increases one unit, the gaze durations on the currently fixated word N decreases 1.325 (after power transformation). When reading English first, the coefficient value is -0.795 ($p < 0.001$). The coefficient value for the Upper Intermediate group when reading Chinese first is -0.667 ($p < 0.001$), which also means that as the word length of the preceding word N-1 increases one unit, the gaze durations on the currently fixated word N decreases 0.667; when reading English first the coefficient value is -1.706 ($p < 0.001$).

In addition to the length of word N-1, the frequency of word N-1 is also found significant to predict the variance of the gaze durations on word N. Firstly, we will examine different patterns among three groups in Figure 24.

Figure 24

The effect of the frequency of the previous word N-1on the gaze durations on word N for two Chinese groups with different reading orders compared to the native group



The x-axis depicts the scaled value of the frequency of the preceding word N-1. The y-axis depicts gaze durations on the currently fixated word.

From Figure 24, we can see a similar pattern between the Advanced group and the Upper Intermediate group as they both showed a general trend of decline. Our model, reported in full in in Appendix 5 on page 369, finds only a statistically significant relationships between the frequency of the previous word N-1 and the gaze durations on the currently fixated word for the native group and for the Upper Intermediate group who read English first. This indicates that for native English speakers, higher frequency of the previous word facilitates quicker processing of the current word, showcasing their fluency in the language. Their familiarity with the language provides them with a distinct advantage, enabling them to read seamlessly without significant interruptions.

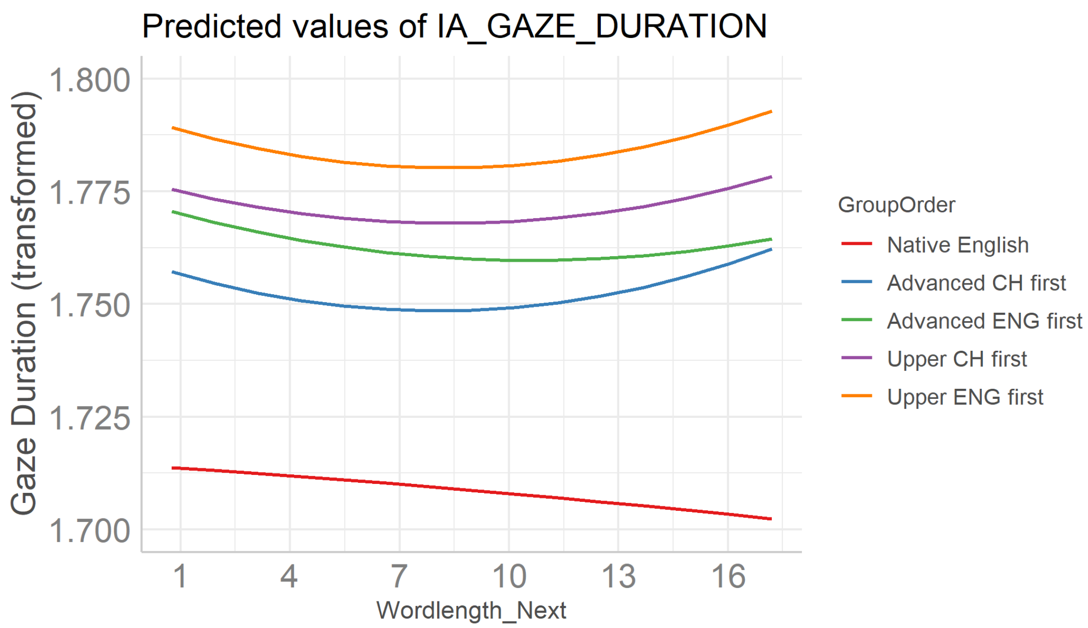
On the other hand, non-native speakers, especially the Upper Intermediate group that read in English first, appear to be influenced by the frequency of the previous word N-1.

5.2.5 The Effects of the Next Word N+1

Not only the length and frequency of word N-1 were found to affect the variance of gaze durations on word N, the effects of the length and frequency of the word N+1 were also statistically significant. In the following parts, we will illustrate the relationships between the properties of word N+1 and gaze durations on the currently fixated word N. Then, we will compare the patterns of the three groups based on the plotted correlations.

Figure 25

The effect of the length of the next word N+1 on the gaze durations on word N for two Chinese groups with different reading orders compared to the native group

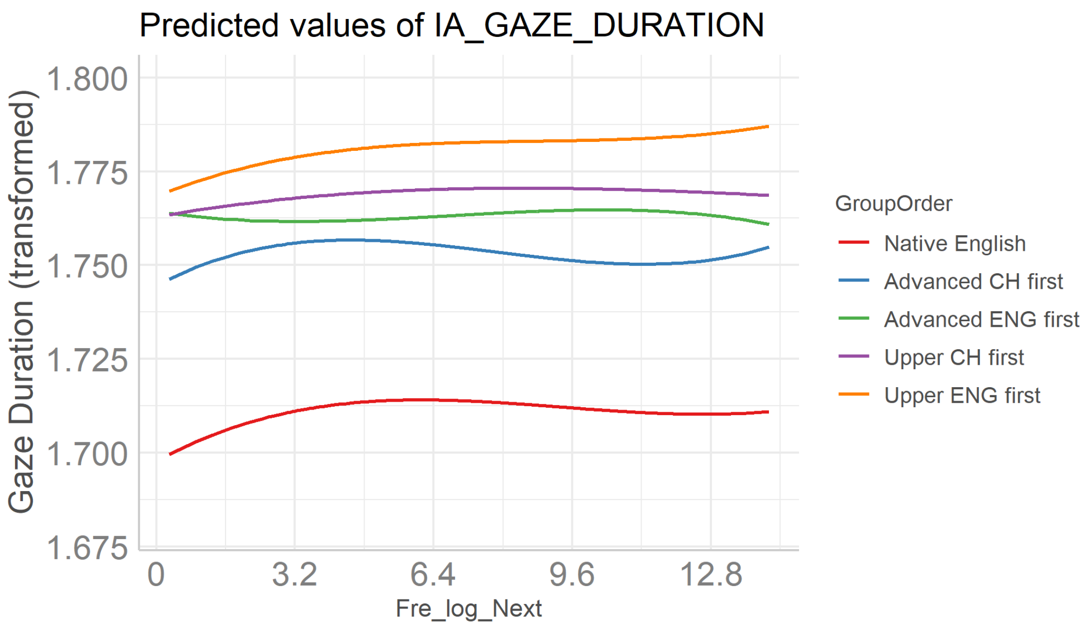


The x-axis depicts the word length of the next word. The y-axis depicts gaze durations on the currently fixated word. As the modelling results show (fully reported in Appendix 5 on page 369), there are statistically significant linear correlations between the length of word N+1 (Wordlength_Next) and the gaze durations on word N. More specifically, the coefficient value of the native group is negative, -0.518 ($p = 0.02$), meaning that as the length of the upcoming word increase one unit, for native readers, the mean gaze duration decreases with 0.518. A statistically significant negative correlation can also be found for the Advanced group who read Chinese first (the coefficient value is -0.785, $p = 0.045$) and when they read English first (the coefficient value is -0.1, $p = 0.001$). Statistically significant relationships were also found in the Upper Intermediate group when they read Chinese first (the coefficient value is -0.666, $p = 0.03$) and when they read English first. What is worth noting here is the mean gaze durations of both Chinese groups are greater than those of the native group. In other words, we found a stronger effect of the length of the next words on the Advanced group and the Upper Intermediate groups as L2 readers than on the native group as L1 readers of English.

In Figure 26, we compare the correlations between frequency of the word N+1 and gaze durations on the currently fixated word N and how they differ among the three groups. The x-axis depicts the scaled value of the frequency of the next word N+1.

Figure 26

The effect of the frequency of the next word N+1 on the gaze durations on word N for two Chinese groups with different reading orders compared to the native group



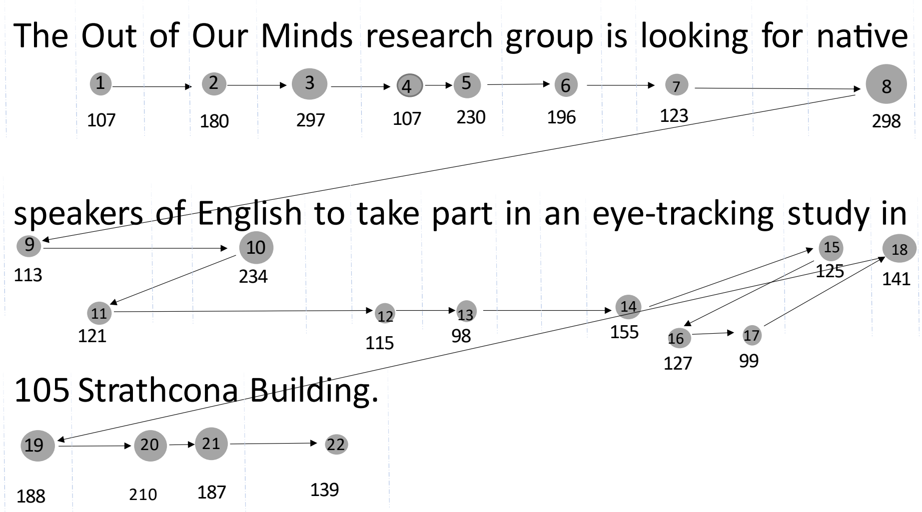
We found a statistically significant relation for the native group between the frequency of the next word and the gaze durations on the currently fixated word, and for the Advanced group when they read Chinese first. More specifically, there is statistically significant quadratic relation between the frequency of the next word N+1 and gaze durations on word N for native readers where the coefficient value is positive, 0.361 ($p = 0.014$). This positive number tells us that as the next word's frequency increases, the time spent on the current word dose not just increase for the Advanced Chinese group, the coefficient value is also positive, 0.517 ($p = 0.038$). It can be tentatively concluded that the effect of the frequency of the next word was only found for the native group, and for the Advanced group only when they read Chinese first.

Chapter 6: The English Reading Study - Total Reading Time

In chapter 5, we reviewed gaze durations, defined as the sum of all the fixations made in a region until the eye leaves the region to the right. In this chapter, we will focus on the third frequently used eye-movement measure, total reading time. Total reading time is the sum of all fixations made on a word (word N), which includes both first fixation durations and gaze durations and fixations caused by subsequent re-reading. Here re-reading refers to all fixations made on the word N during the reading task. Total reading time is therefore considered a late measure and is likely to be affected by contextual and discourse-level factors, which come in at the late stages of reading process. In Figure 27, the total reading time on the word ‘eye-tracking’ equals the total of fixations 14+16+17 (in dark grey circles). Notice that after fixation 14, the eye moved to the right and out of the word ‘eye-tracking’, then the word ‘eye-tracking’ received a re-reading with fixations 16 and 17. Therefore, the total reading time on word ‘eye-tracking is 381 milliseconds (the sum of 155 ms, 127 ms and 99 ms). Similarly, the total reading time on ‘speakers’ is the sum of fixations 9 and 11, which equals 234ms. A more detailed and complete version based on the hypothetical eye-movements example can be found in Appendix 3G.

Figure 27

Hypothetical eye-movements (fixations and saccades) during silent reading



Note. Each word is regarded as an Interest Area (IA) with a dashed line separating them. Grey circles indicate fixations and arrows show saccades with various directions and lengths. Numbers (1-22) in circles show the order of fixations. Fixations are given in milliseconds below the word on which they occurred for the purpose of presentation.

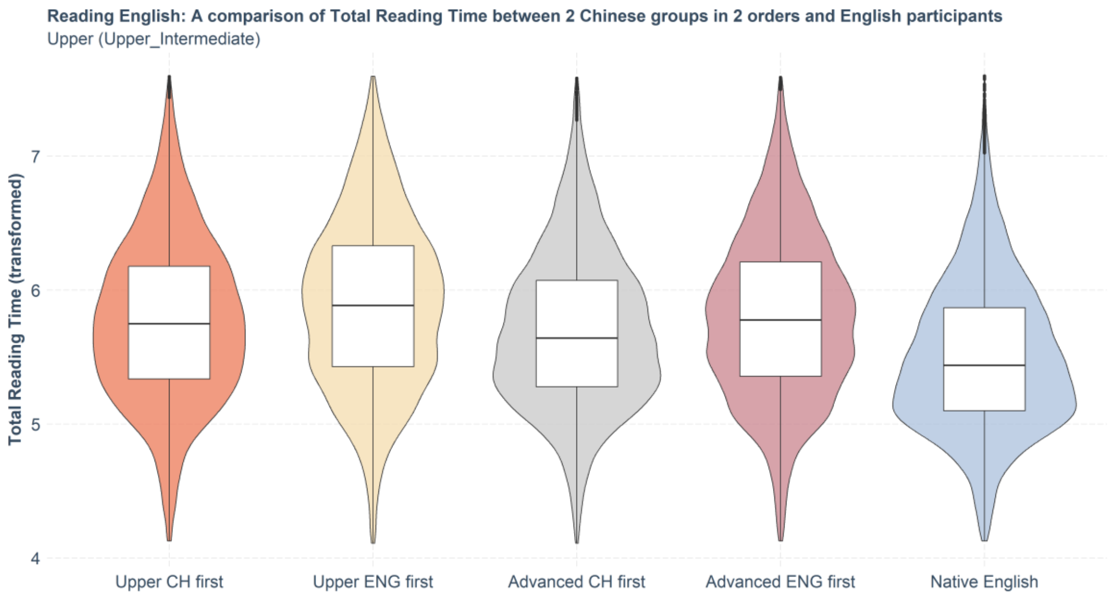
Total reading time, as a late measure, not only reflects lexical factors, but are also influenced by contextual, syntactic, or discourse-level properties of what is being read. For example, syntactic ambiguity can lead readers to make longer total fixations on a word, and more regression to the prior context as the reader needs to check their comprehension of the previous words.

6.1 Preliminary Data Analysis

As in the previous two chapters, we start by mapping out the possible effect of reading English first, or after having read similar texts in Chinese, on the eye-movement measure. In this section, we will first visualise and compare the total reading time of both groups of Chinese participants in both reading conditions to the result of the native group. To achieve this, five violin plots (Figure 28) are created to present how the total reading time on the currently fixated word N of the two Chinese groups and the native group were influenced by different reading orders.

Figure 28

Violin plots of total reading time of two Chinese groups and the native group



Note. The y-axis represents the values of total reading time after log transformation. From the left to the right, the x-axis lists the Upper Intermediate groups in both reading orders, the Advanced group in both reading orders and the native group.

For the Upper Intermediate group and the Advanced group, the means of the total reading time were lower when they read Chinese texts first. Among all, the native group still has the lowest mean value of total reading time. Table 9 presents the values of the test we ran to determine whether the differences between groups were statistically significant.

Table 9

Total reading time of both Chinese groups in both reading orders versus the native group

Group	Mean	Median	SD	MAD
Upper CH first	5.775	5.749	0.605	0.623
Upper ENG first	5.894	5.886	0.637	0.666
Advanced CH first	5.698	5.642	0.582	0.584
Advanced ENG first	5.796	5.776	0.613	0.636
Native English	5.506	5.438	0.565	0.557

Two z-tests were run with the null hypothesis that the means of the total reading time recorded for the Advanced group and the Upper Intermediate group in both conditions would be the same. For the Upper Intermediate group ($z = -15.375$, $p < 0.05$) meaning that the means of the total reading time of the Upper Intermediate group in two conditions are statistically significant different. The same result is found for the Advanced group ($z = -12.171$, $p < 0.05$). In other words, the reading order statistically significantly influences the total reading time for both Chinese groups.

To obtain more details, we ran z-tests to compare the means of the Upper Intermediate group and the Advanced group when they both read Chinese first. The z-test result is statistically significant ($z = 9.6078$, $p < 0.05$). We obtained a similar result when we compared the means of the Upper Intermediate group and the Advanced group when they read English first. The z-test result is also statistically significant ($z = -12.574$, $p < 0.05$). In the Upper Intermediate group, the mean value of participants who read Chinese first decreased with 0.119, while the decrease for the Advanced group is 0.098:

compared with the Upper Intermediate group who has generally lower language proficiency and L2 exposure, the Advanced group benefit less from the help of reading Chinese texts first as their total reading time decreases less.

The standard deviation reveals interesting results regarding the variance of the total reading time of both groups in different reading orders. The standard deviation can be the indication of the variance of a value. Basically, a small standard deviation means that the values in a statistical data set are close to the mean (or average) of the data set, and a large standard deviation means that the values in the data set are farther away from the mean. Both Chinese groups had smaller standard deviations in total reading time while reading English if they had read Chinese first. It means that this sequential language experience led to more consistent and predictable reading patterns.

6.2 Statistical Modelling the Total Reading Time data

In this section, data for the total reading time were analysed using a linear mixed-effects model. This model was fitted using the lmer function from the lme4 package (Version 1.1-26) in the R Environment for Statistical Computing (Version 3.3.1).

In what follows, we will examine how different types of properties affect the total reading time of three groups. The first type includes properties at the word-level. We begin with properties of the currently fixated word (word N) by taking its length and frequency into account. Furthermore, length and frequency of word N’s neighbouring words, N-1, and N+1, were also added into the model to test their possible influences on the total reading time of the currently fixated word. The second type of property is situated at the text level, the Scaled_Word_Story_Order which is the same one we used in models predicting first fixation durations and gaze durations.

Instead of directly fitting the model to the original data, we scaled the values of all properties at word level (length and frequency) to facilitate model fitting. For the same reason, we scaled the value of Word_Story_Order into Scaled_Word_Story_Order. After completing the pre-processing steps outlined above, the variables of interest were ready to be used for modelling.

Table 10

A complete list of variables included in the most parsimonious model to predict the total reading time on word N in reading English

Property Types	**Variable Names**	**Explanation**
	Wordlength_N	the length of the currently fixated word N
	Fre_log_N	the frequency after logarithm of the currently fixated word N
Word-level Properties	Wordlength_Prev	the length of the word to the left of the currently fixated word, i.e., word N-1.
	Wordlength_Next	the length of the upcoming word, N+1
	Fre_log_Prev	the frequency of the word to the left of the currently fixated word, i.e., word N-1
	Fre_log_Next	the frequency of the upcoming word, N+1
Text-level Property	Scaled_Word_Story_Order	the combined order of a word in a story and the order of a story in the reading study

The specification of the final best model is:

```
IA_TOTAL_READING_TIME_LOG~
    CEFRGroups/(
    poly(Scaled_Word_Story_Order,3) +
    poly(Wordlength_N, 3) +
    poly(Fre_log_N, 2) +
    poly(Wordlength_Prev,2)+
    poly(Wordlength_Next,2)+
    Fre_log_Prev+
    poly(Fre_log_Next,2))+
    (1|Participant_ID) +
    (1|Story_ID) +
    (1|Word_ID)
```

The model has a total explanatory power of 0.33, which means that it can predict 33% of the variance in total reading time of Chinese and English participants. The next section discusses all fixed effects in the model for predicting total reading time that are statistically significant, as determined by the test statistic. We have visualised the results, which are presented separately, to demonstrate how these correlations differ across three English levels and durations of stay in the UK.

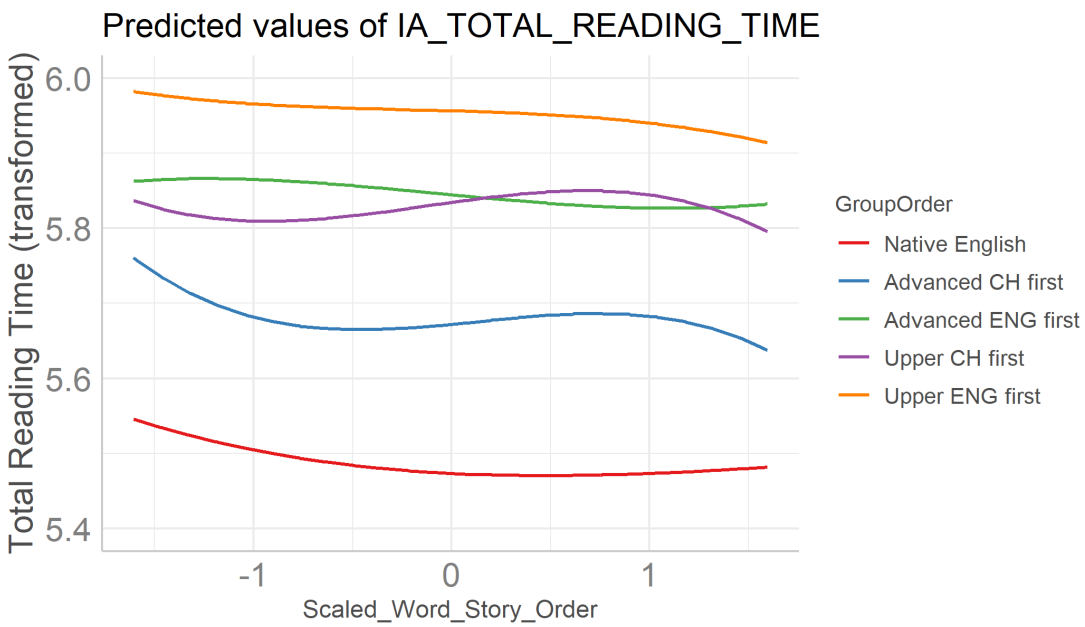
6.2.1 The Order Effect

The power transformed and scaled total reading time in reading English texts is presented in Figure 29 according to the model's predictions of the scaled order of the currently fixated word and the total reading time on this word. More specifically, we controlled how the word order affect the total reading time of two Chinese groups and the native group differently.

The plot in Figure 29 shows the correlations between the Scaled_Word_Story_Order and the total reading time on word N based on the results of the model. The x-axis depicts the scaled value of the word order and story order in the plot regarding Scaled_Word_Story_Order. The range of the value on the x-axis is from -1.6 to 1.6 (after scaling), and the range of the value on the y-axis is from 5.4 to 6 (after power transformation).

Figure 29

The effect of the Scaled_Word_Story_Order on the total reading time on word N for two Chinese groups in reading English with different reading orders compared to the native group



The full model results (in Appendix 6 on page 374) show that, at the linear level, the relationships between Scaled_Word_Story_Order and total reading times on the currently fixated word N are statistically significant for the native group, the Advanced group in both reading orders and for the Upper Intermediate group only in the case when they read English first. For the native group, the Estimates value is -4.972, which means as the Scaled_Word_Story_Order increases one unit, the total reading time on word N decreases 4.972 (after log power transformation): as the word occurs closer to the end of a story and the end of the reading study, the total reading time on it gets shorter.

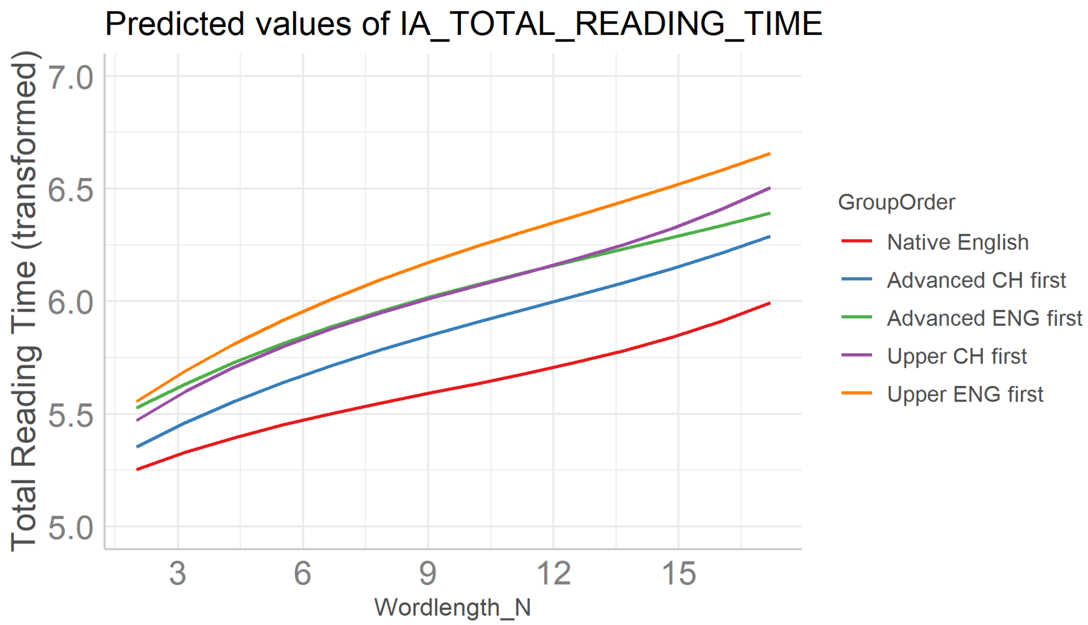
For native speakers reading English as L1, the total reading time on a word is greatly impacted by word position. We found a statistically significant effect of the word order on the total reading time of the Advanced group if they read Chinese first but for the Upper Intermediate group, we found an effect regardless of which language they read first. Among the three groups, the native group (the red line) has the lowest total reading time, which shows that the native group as L1 readers needed shortest total reading time during the reading experiments. The lines of the Advanced group and the Upper Intermediate group are close, and the difference is not statistically significant (see full results in Appendix 6 on page 374).

6.2.2 The Effect of the Length of Word N

In this section, we will present and explain the relationships between length of the currently fixated word N and total reading time on word N for all three groups in both reading orders as shown in Figure 30.

Figure 30

The effect of the length of the currently fixated word N on the total reading time on word N for two Chinese groups with different reading orders compared to the native group



The x-axis indicates the length (number of letters) of the currently fixated word. The y-axis depicts total reading time (with a range from 5 to 7).

Figure 30 illustrates various levels of positive associations between word length and total reading time. Among the three groups, the native group (in red) shows a general lower total reading time throughout the process. All five lines exhibit a rising trend, as all three groups had a longer total reading time on words with more letters (which are visually longer), regardless of whether they read Chinese first or English first. It means that we can see a clear relation between word length and total reading time in Chinese participants as L2 readers of English and the native readers' eye-movement.

In Figure 30, some interesting patterns can be found for both Chinese groups with both reading orders. Firstly, the Advanced group who read Chinese first (the blue line) is the lowest among the four. The Upper Intermediate group who read English first (the orange line) had the longest total reading time of all. Between the two lines, we see the overlapping trend of the Upper Intermediate group who read Chinese first and the Advanced group who read English first. Yet, we can still see difference between the two: when the words are shorted than 4 letters, the influence of the length of the currently fixated word N was stronger for the Advanced group but when the words were longer than 12 letters, we find the opposite pattern as the effect was stronger for the Upper Intermediate group.

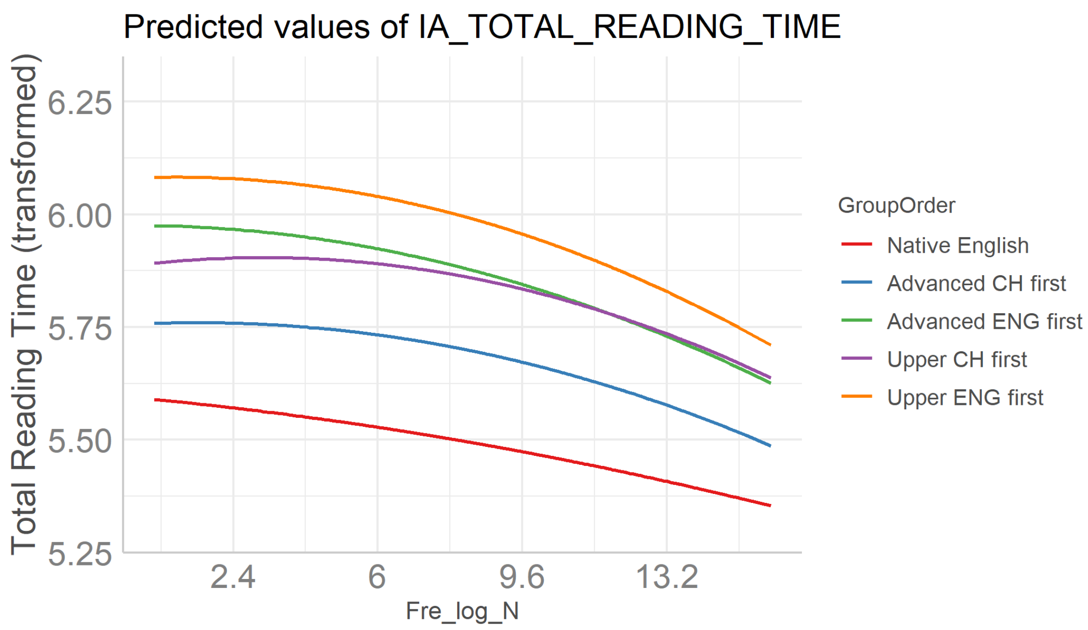
After we analyse different patterns in the plot for the native, the Advanced group and the Upper Intermediate group, it is necessary to find whether these predictors are statistically significant in the model. A full list of results of the model can be found in Appendix 6 on page 374. Note that in Appendix 6 if the predictor is affixed with 1, the relation is linear; if the Predictor is affixed with 2, the relationship is quadratic; if 3, cubic. It is worth noting that all three groups have a statistically significant positive correlation at the linear regression level. More specially, the Estimate indicate that the regression coefficient for native readers is 38.369 ($p < 0.001$). For the Advanced group reading Chinese first it is 54.531 ($p < 0.001$), for those reading English first it is 53.337 ($p < 0.001$). For the Upper Intermediate group reading Chinese first it is 58.189 ($p < 0.001$) and for those reading English first it is 67.077 ($p < 0.001$). These positive coefficients indicate that for all three groups and both reading orders, as the word length of the currently fixated word increases with one unit, the total reading time on this word will increase 1) for native readers, 38.369 (note that this value, after undergoing a power transformation, should be considered as a reference point for all subsequent values); 2) for the Advanced group who read Chinese first, 54.531; 3) for the Advanced group who read English first, 53.337; 4) for the Upper Intermediate group who read Chinese first 58.189; 5) for the Upper Intermediate group who read English first 67.077. As can be seen from the varied values of the three groups in both reading orders, at the linear level, the native group showed the smallest effect of word length on the total reading time of the currently fixated word. The Advanced group showed a stronger influence of the length of the currently fixated word if they had read Chinese first. However, the total reading time of the Upper Intermediate group was influenced by the length of the currently fixated word more in the case when they read English first.

6.2.3 The Effect of the Frequency of Word N

Figure 31 shows the relationship between the frequency of the currently fixated word and the total reading time for the three groups of participants, and for the Chinese participants the two reading orders are shown separately. In the following plot, we see that as the frequency of the currently fixated word increases, the total reading time of all three groups, in both orders, decreases.

Figure 31

The effect of the frequency of the currently fixated word N on the total reading time on word N for two Chinese groups with different reading orders compared to the native group



The x-axis indicates the frequency of the currently fixated word. The y-axis depicts total reading time.

Appendix 6 on page 374 contains the model in all its detail. Here we zoom in and compare the differences between groups based on the relationships between frequency and total reading time. When it comes to the linear relationship, the coefficient values of all three groups and both reading orders are statistically significant and negative (-16.417 for the native group; -20.279 for the Advanced group who read Chinese first and -25.576 for the Advanced group who read English first; -19.744 for the Upper Intermediate group who read Chinses first and -27.562 for those who read English first. All values are statistically significant with $p < 0.001$. The negative coefficient signals a negative correlation between word frequency and total reading time: as the frequency of the words increases, reading time on it decreases. Nonetheless, the coefficient values vary significantly between groups, most notably between the native group and the two Chinese groups. The native group has a coefficient value of -16.36, which means that when the frequency of the currently fixated word increases by one unit, the total reading time on it decreases by 16.36 (after power transformation). However, as for the Advanced group, increasing the frequency of the currently fixated word by one unit resulted in a higher drop when they read Chinese first, and an even stronger effect of the frequency of the currently fixated word was found when they read English first. As for the Upper Intermediate group, which has a lower level of L2 proficiency than the Advanced group, a unit of increase resulted in a 19.744 drop in total reading time and a strong effect of the frequency of the currently fixated word was found when they read English first.

The linear effects of this variable on the of three groups indicate that the frequency of the currently fixated word had the greatest effect on the total reading time of the Upper Intermediate group who read English first, next on the Advanced group who read English first, followed by the Advanced group when they read Chinese first, and finally on the Upper Intermediate group when they read Chinese first.

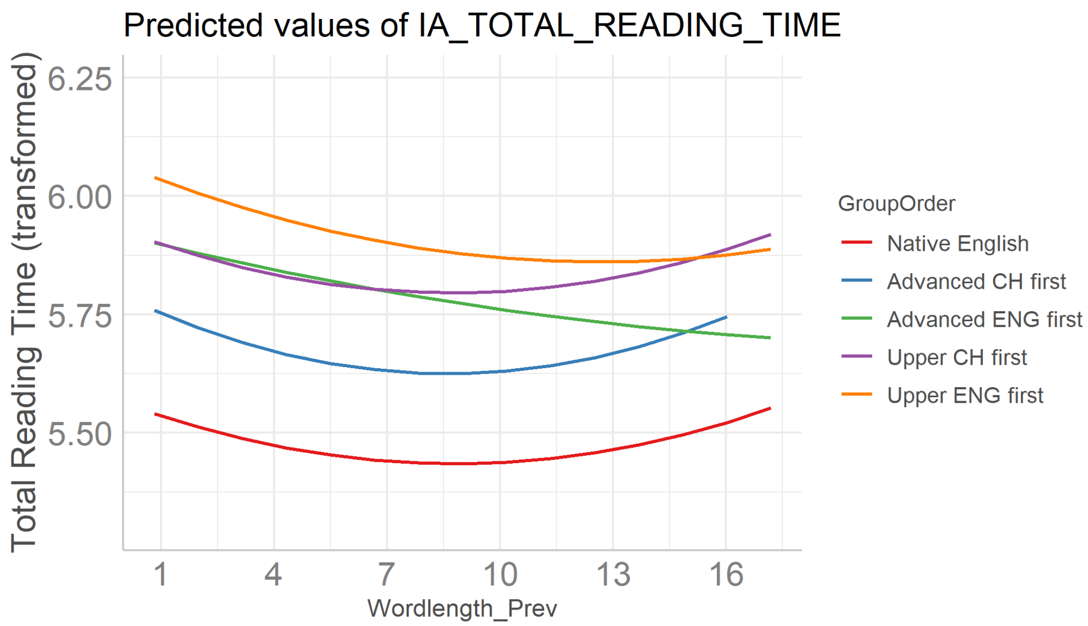
Returning to Figure 31, we can see that the total reading time of the native group is overall lower than that of the two Chinese groups. Besides, among the two Chinese groups in both reading orders, the Advanced group reading Chinese first had the shortest total reading time, and the Upper Intermediate group reading English first had the longest total reading time. Again, similar to what we found regarding the effect of word length, the difference between the Advanced group who read English first and the Upper Intermediate group who read Chinese first is marginal. However, the effect of the frequency of the currently fixated word is stronger for the Advanced group who read English first when the frequency of the currently fixated word is lower than 9.6 as the green and purple lines indicate in Figure 31.

6.2.4 The Effects of the Previous Word N-1

As previously stated, the length of word N-1(Wordlength Prev) and the frequency of word N-1(Fre_log_Prev) were also added as fixed effects to predict the currently fixated word's total reading time. Figure 32 illustrates the correlations between the length of word N-1 and total reading time on the currently fixated word N. The x-axis depicts the word length of word N-1 and the y-axis shows the total reading time (after log transformation). The total reading time of the native group is always the lowest (the red line). Visually the five lines in Figure 32 can be divided into two groups. The first group is made up of the lines indicating the relationships between the length of the previous word and the total reading time on the currently fixated word N of the Native group (the red line), the Advanced group reading Chinese texts first (the blue line), and the Upper Intermediate group reading Chinese texts first (the purple line). All three lines show a ‘U-shaped’ pattern. It means that as the word length of the previous word increases from 1 letter to 8 letters, the total reading time on the currently fixated word gets shorter, but when the word length exceeds 8 letters, as the word length of the previous word increases, the total reading time increase accordingly. A very distinct pattern can be found for the orange line and the green line that represent the two Chinese groups who read English first. For these groups, as the word length of the previous words increases, the total reading time on the currently fixated word decreases.

Figure 32

The effect of the length of the previous word N-1 on the total reading time on word N for two Chinese groups with different reading orders compared to the native group



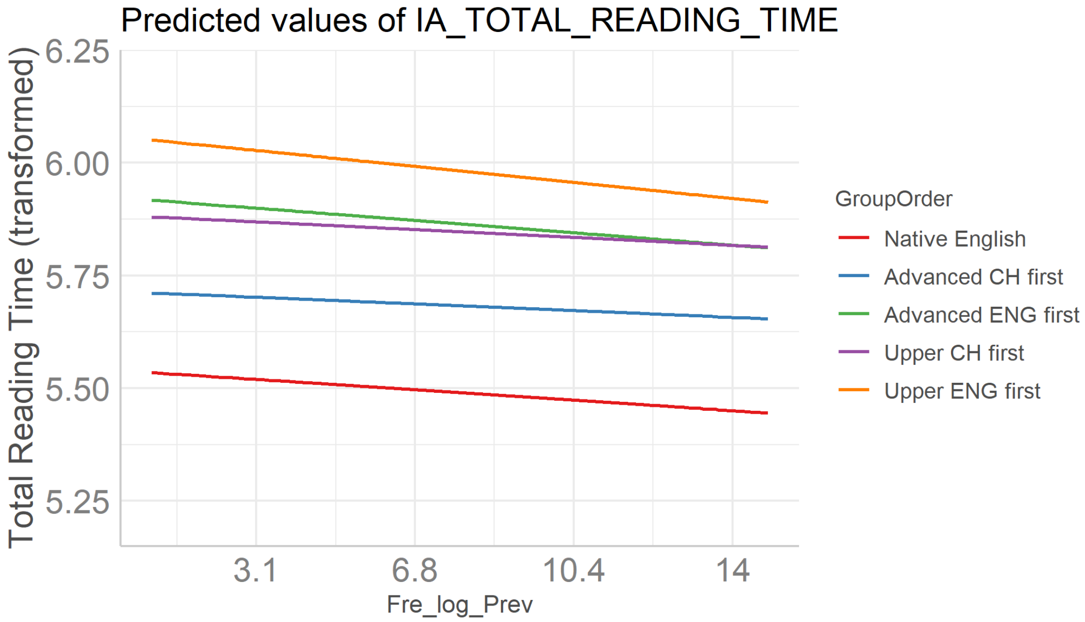
The x-axis indicates the length (number of letters) of the previously fixated word, scaled and reversed. The y-axis depicts total reading time.

At the linear level, both Chinese groups in both reading orders showed a statistically significant negative correlation. The Advanced group who read Chinese first has a coefficient of -11.895 ($p < 0.001$), which means that as the word length of the preceding word N-1 increases one unit, the total reading time on the currently fixated word N decreases with 11.895; the coefficient value when they read English first is -12.972 ($p < 0.001$), which means that as the word length of the preceding word N-1 increases one unit, the total reading time on the currently fixated word N decreases with 12.972. The coefficient value for the Upper Intermediate group when they read Chinese first is -9.695 ($p < 0.001$), which also means that as the word length of the preceding word N-1 increases one unit, the total reading time on the currently fixated word N decreases 9.695; the coefficient value in case they read English first is -15.697 ($p < 0.001$), which means that as the word length of the preceding word N-1 increases one unit, the total reading time on the currently fixated word N decreases 15.697. For the group of native English participants, the coefficient value is also significant, which is -9.516 ($p < 0.001$), which means that as the word length of the preceding word N-1 increases one unit, the total reading time on the currently fixated word N decreases with 9.516.

In addition to the length of word N-1, the frequency of word N-1 is also statistically significant in our model that predicts the variance of the total reading time on word N. Here we report our results based on Figure 33.

Figure 33

The effect of the frequency of the previous word N-1 on the total reading time on word N for two Chinese groups with different reading orders compared to the native group



The x-axis depicts the log-transformed frequency of the preceding word N-1 and the y-axis shows total reading time (after log transformation).

Firstly, we will examine the patterns of all three groups on the right panel in Figure 33. We can observe a general declining pattern for the native group, which means that as the word frequency of the previous word N-1 increases, the total reading time on the currently fixate word N gets shorter. We can see the same pattern for the Advanced group and the Upper Intermediate group in both reading orders as they both show a general trend of decline. The total reading time of the native group is the lowest while the total reading time of the Advanced group who read English first and the total reading time of the Upper Intermediate group who read Chinese first are very similar to each other.

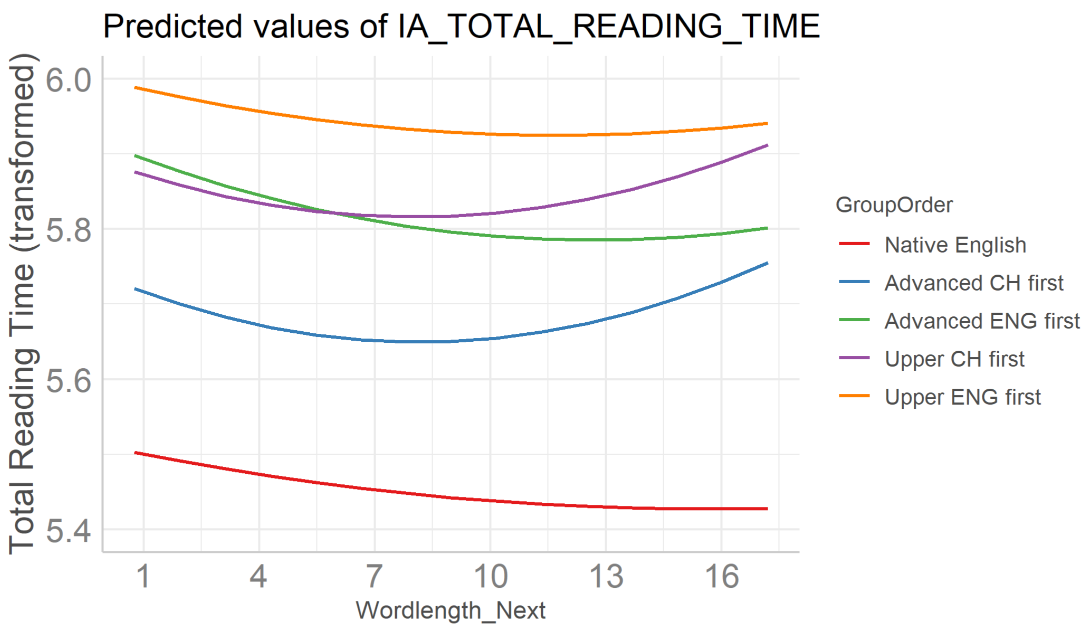
Next, we will move on to examining the results of the model detailed in Appendix 6 on page 374. The linear correlation between the frequency of word N-1 on the total reading time of N is statistically significant for native readers which has an estimation value as -0.023 ($p < 0.001$). This negative value indicates that as the frequency of the preceding word increases, the total reading time for the subsequent word tends to decrease ($p < 0.001$). This inverse relationship suggests that more common antecedent words facilitate quicker integration and processing, thereby reducing the total time spent reading the subsequent word. For the Upper Intermediate group, there are statistically significant negative correlations between the frequency of the preceding word N-1 and the total reading time on the currently fixated word N in both reading orders. The coefficient value for the Upper Intermediate group who read Chinese first is -0.017 ($p < 0.001$), which means that as the frequency of word N-1 increase one unit, the total reading time on the currently fixated word N decreases 0.017 (after log transformation), while the value is -0.036 if they read English first. The coefficient value for the Advanced group is only statistically significant when they read English first. What is more, the influence of the frequency of the previous word N-1 is stronger for the Upper Intermediate group when they read English first.

6.2.5 The Effects of the Next Word N+1

The model's outcomes reveal that not only the characteristics of word N-1 have a discernible impact on predicting the variation in total reading time for the currently fixated word, but the length and frequency of word N+1 also demonstrated an effect. In the upcoming sections, we will initially present and scrutinise the noteworthy linear and polynomial associations between the attributes of word N+1 and the total reading time for word N, independently for each of the three groups. Subsequently, we will evaluate and contrast the observed patterns among these three groups based on the correlations illustrated in the plots.

Figure 34

The effect of the length of the next word N+1 on the total reading time on word N for two Chinese groups with different reading orders compared to the native group



The x-axis indicates the length (number of letters) of the upcoming fixated word. The y-axis depicts total reading time.

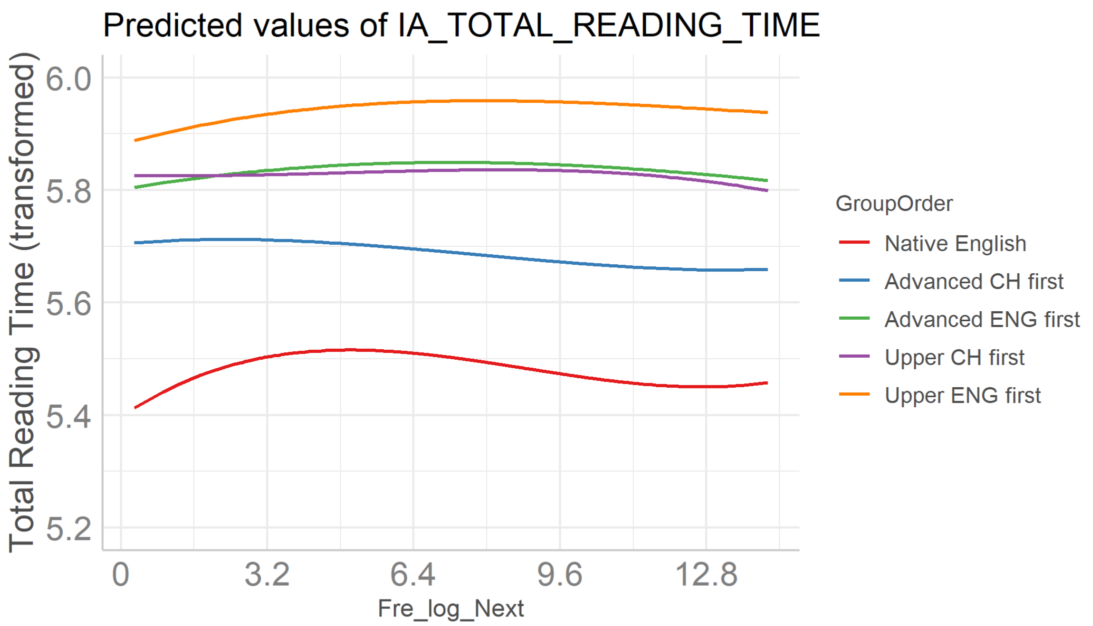
Figure 34 shows the relationships between length of word N+1 and the total reading time on word N for the three groups in both reading orders; the x-axis indicates the length (number of letters) of the currently fixated word. Figure 34 reveal that the total reading time on word N for the native group is the lowest, but quite similar values can be found for the Advanced group that read English first and for the Upper Intermediate group that read Chinese first when the word length of the next word is less than 7 letters; the differences get larger when the length of the upcoming word gets longer than 7 letters.

There are some interesting results revealed by the model results. Firstly, as shown in Appendix 6 on page 374 , the word length of the next word N+1 is statistically significant for all three groups in both reading orders at the linear component. More specifically, the Estimates value for the native group is -5.941 ($p < 0.001$), which means that as the length of the next word increases one unit, the total reading time on the currently fixated word N decreases 5.941 (after log transformation). For the Upper Intermediate group, the Estimates value is smaller at -5.145 ($p < 0.001$) for those who read Chinese first and -5.779 for those who read English first. The value for the Advanced group is larger at -6.197 ($p = 0.013$) if they read Chinese first and -9.859 if they read English first. Put differently, the effect of the length of the next word is found to be much stronger for the Advanced group in both reading orders than for the Upper Intermediate group and the native group. The quadratic components are only statistically significant for the Chinese groups if they read Chinese first (see the blue and purple line in Figure 34). It means that with the help of reading Chinese first as L1, L2 readers of English showed stronger effect of the length of the upcoming word on their total processing time on the currently fixated word. The nature of the quadratic components suggests that the influence of the length of the next word on their current reading speed does not increase steadily as in a linear relationship but rather changes more dramatically, possibly increasing or decreasing at a faster rate. This dynamic changing indicates a more complex relationship between the length of the next word and the total reading time on the currently fixated word.

Not only the length of the next word has a statistically significant influence on the total reading time of the currently fixated word N, but also frequency of the next word (see Figure 35).

Figure 35

The effect of the frequency of the next word N+1 on the total reading time on word N for two Chinese groups with different reading orders compared to the native group



The x-axis indicates the frequency of the upcoming fixated word. The y-axis depicts total reading time.

However, the influence can only be detected in native readers (Appendix 6), we can see that for the native group, the Estimates value at the linear component is -4.676 ($p = 0.002$), which means that as the frequency of the next word N+1 increases by one unit, the total reading time on the currently fixated word decreases 4.676.

6.3 Discussion

In this chapter, we ran statistical tests to compare the total reading times of the three groups with various English language proficiency levels with word order as the control variable. A related previous study (Kuperman et al., 2018) investigated the impact of word position in the text on the reading behaviours and they found that words further into the text led to higher skipping and regressions rates and longer regression path durations. Our result is in line with the findings as for all three groups and two reading orders as there are statistically significant negative correlations between the word order and total reading time on the currently fixated word.

Our results show language proficiency and previous reading in L1 can be used as an indicator to differentiate readers' eye movement results, more specifically, the total reading time. In other words, the native group as L1 readers had the lowest total reading time. Between the two Chinese groups, the total reading time of the Advanced group is overall shorter than that of the Upper Intermediate group, and the difference between these two groups is statistically significant.

Furthermore, our observations concerning total reading time reveal an interesting trend: when the Upper Intermediate group starts with reading Chinese as L1, their reading behaviour becomes remarkably similar to that of Advanced readers, as illustrated in Figure 35. Reading Chinese first seems to play a crucial role in bridging the gap between these two Chinese proficiency groups. Recall that total reading time, as a measure, primarily captures the time spent on comprehending the overall context and meaning of the text, encompassing activities such as sentence integration, inference-making, and grasping the broader narrative. In contrast, early measures including first fixation durations and gaze durations are about lexical processing and pertain to the fundamental recognition and interpretation of individual words and their meanings within the text. This includes activities like word recognition, vocabulary comprehension, and syntactic parsing. Our findings suggest that reading Chinese as L1 exerts a significant influence on the participants' overall reading strategy, potentially shaping their way of engagement with the text in L2 reading.

Our result is in line with earlier findings stating that reading behaviours in bilinguals are modulated by some elements, including reading ability. This is because bilinguals generally have reduced L2 vs. L1 exposure, and consequently, reduced L2 vs. L1 reading ability, therefore, bilinguals generally exhibit both reduced global and local measures of L2 vs. L1 reading performance (Whitford et al., 2016). We found that the Upper Intermediate group and the Advanced group as L2 readers had longer total reading time as a late eye-movement measure as their English reading ability is lower than that of the native group. An interesting finding from our descriptive analysis is that the Advanced group with higher L2 proficiency level had shorter total reading time than that of the Upper Intermediate group.

In the modelling section, we reported the statistically significant impact of the length and frequency of the currently fixated word on the total reading time on it. More specifically, we found significant positive relationships between the length of the currently fixated word and the total reading time: as the words get longer, the total reading time spent on the word gets longer accordingly. Also, as the word frequency of the word N increases, the total reading time on this word gets shorter, as indicated by a statistically significant negative correlations in the model. Our results are in line with what has been discussed in previous eye-movement research in reading (Just & Carpenter, 1980; Reichle et al., 1998a). However, the novel result of our study is that we found these statistically significant relationships both in L1 and the L2 reading groups: the total reading time of both groups was statistically significantly modulated by the word length and the frequency.

Besides the influence of the currently fixated word and how it modulates the total reading time, our model also provides statistical evidence to show the effect of the neighbouring words on the total reading time on the currently fixated word. We found a statistically significant influence of both the length and the frequency of the neighbouring words N-1 and N+1, which agrees with previous research (see introduction).

In addition to word level properties, we also found an effect of the word order on the total reading time. Our findings underscore the positive impact of beginning with Chinese versions on the overall performance of second language (L2) readers who exhibit lower proficiency levels and have had more limited exposure to L2 reading. It appears that initiating their reading experience with Chinese texts provides a valuable boost in terms of their reading behaviours. This observation suggests that for individuals at this proficiency level, the sequence in which they encounter languages can significantly influence their reading outcomes. Reading Chinese first seems to create a beneficial foundation for their subsequent engagement with the second language, ultimately enhancing their overall reading behaviours. This insight has implications for language education and pedagogy, emphasising the importance of strategic language sequencing to optimise learning outcomes for learners with varying levels of proficiency and exposure.

Chapter 7: Main Findings in Reading English

In the previous three chapters, we reported the results of the statistical description and analysis of three eye-movement measures taken while Chinese learners of English read English as L2. We focused on First Fixation Duration (Chapter 4), Gaze Duration (Chapter 5), and Total Reading Time (Chapter 6). In this chapter, we aim to wrap up the previous three chapters and list the main similarities and differences among the three groups concerning the three eye-movement measures we reported. Discussions and interpretations will also be provided here.

Recall that in the descriptive analyses in Chapter 4 to Chapter 6 we compared and visualised whether there are statistically significant differences among the three groups of participants, Chinese participants in the Upper Intermediate group and the Advanced group, and native English group. We controlled for the effect of reading order, i.e., whether the readers started with English texts or whether they had read a Chinese version first. Next, we fit linear mixed-effects models to the eye-movement data of both groups of Chinese participants and the native group. We included random effects of Participant_ID, Story_ID and Word_ID, which capture where in the text and where in the experiment the participants were at the time a particular eye movement measure was taken. Including Participant_ID as random effect allows us to allow us to generalise the findings to the population. Nested random effects were included in the model based on the statistically significant and hierarchical differences among the three groups. Furthermore, we explored the non-linear relationships between the independent and dependent variables in the model and tested for possible curvilinear correlations to refine our model and produce a more accurate prediction.

Table 11

A list of variables as predictors that are statistically significant in the models capturing the three eye-movement measures as dependent variables

Property Types	First Fixation Duration	Gaze Duration	Total Reading Time
Scaled_Word_Story_Order	√	√	√
Wordlength_N	√	√	√
Fre_log_N	√	√	√
Wordlength_Prev	√	√	√
Wordlength_Next		√	√
Fre_log_Prev	√	√	√
Fre_log_Next		√	√

The following sections will zoom in on three aspects. In the first section (Section 7.1), we will summarise the effect of the word order as a control variable on the main three eye-movement variables to three groups of participants. Then, Section 7.2 focuses on the effect of the properties of the target (currently fixated) word N on the fixation durations on this word. Section 7.3 and Section 7.4 are about parafoveal processing i.e., effects of the word to the left and to the right of the currently fixated word on the target word. In these sections, we systematically compare the main features of the parafoveal processing of three groups of participants in reading English given their distinct language proficiency levels and exposure.

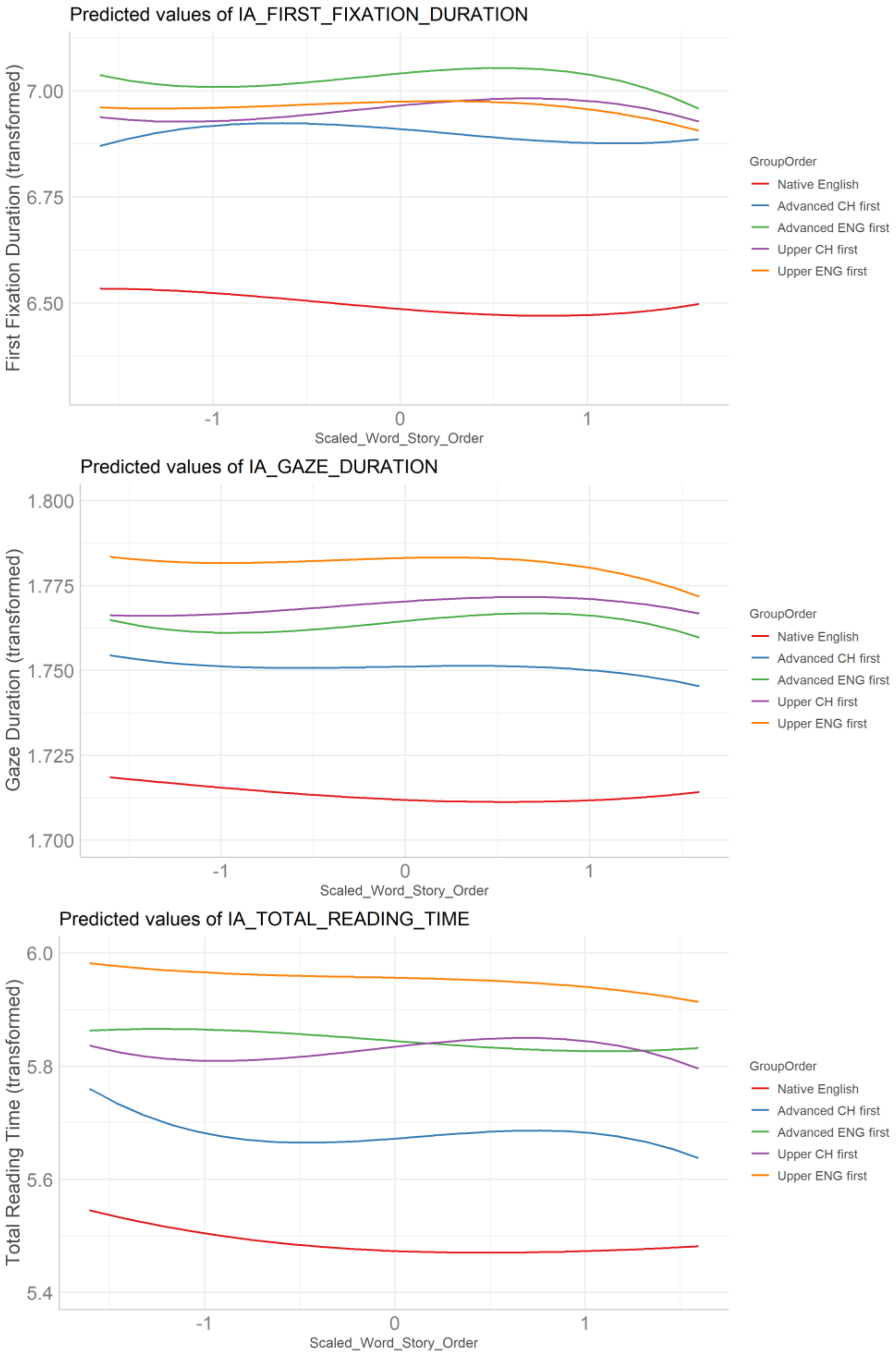
7.1 The Order Effect

Recall that the variable Scaled_Word_Story_Order indicates the combined order of a word in a story and the order of a story in the English reading study. In the models we reported in the previous three chapters predicting the variance of First Fixation

Durations, Gaze durations and Total Reading Time in reading English, the Scaled_Word_Story_Order was found to be statistically significant for the fixation durations of certain groups in various reading orders. This suggests that the position of the currently fixated word in a text and of the text in the reading study significantly affected the three fixation related variables taken while reading English texts. However, what caught our attention is the fact that the different reading orders had different effects on the eye-movement measures of the two different Chinese groups. Figure 36 compares the relations between the Scaled_Word_Study_Order and the three eye-movement measures for all groups in both orders.

Figure 36

Plots of the effect of the Scaled_Word_Story_Order on first fixation durations, gaze duration, and total reading time on word N for all three groups



The measure known as Scaled_Word_Story_Order turned out to be a reliable predictor of the differences in how long readers first fixate on a word, but only for two specific groups: native English speakers and advanced non-native speakers who read

English before other languages in our study (as detailed in Section 4.2.1). Essentially, for native English speakers, the time spent on the initial look at a word got shorter as they progressed through the texts and as the experiment advanced. In other words, they started to read more quickly as they moved toward the end of a story and neared the completion of the experiment.

For advanced learners of English, this pattern of decreasing fixation durations with ongoing reading was only observed when they read English texts first. This suggests that second language (L2) readers who are more proficient and have more exposure to English begin to show reading patterns similar to native speakers, particularly in how the sequence of words and stories influences their reading. The more these advanced L2 readers read, the faster they became at recognising and decoding words.

Interestingly, the effect of word position started to become statistically significant for both Chinese groups only in later eye-movement measures, i.e., Gaze Duration and Total Reading Time. Zooming in on the bottom of the two plots in Figure 36 above, we see that the differences between the two Chinese groups become more pronounced and larger as we move from first fixation duration over gaze duration to total reading time (regardless of reading order). Again, in the first fixation duration plot (the top one in Figure 36), the Advanced group who read English first had the longest first fixation durations. However, in the gaze durations, the Upper Intermediate group took longer time than the Advanced group, regardless of reading order. The same pattern can be found in the total reading time plot, as the total reading time of the Advanced group who read Chinese first is the lowest among the four.

7.2 The Effects of the Word N

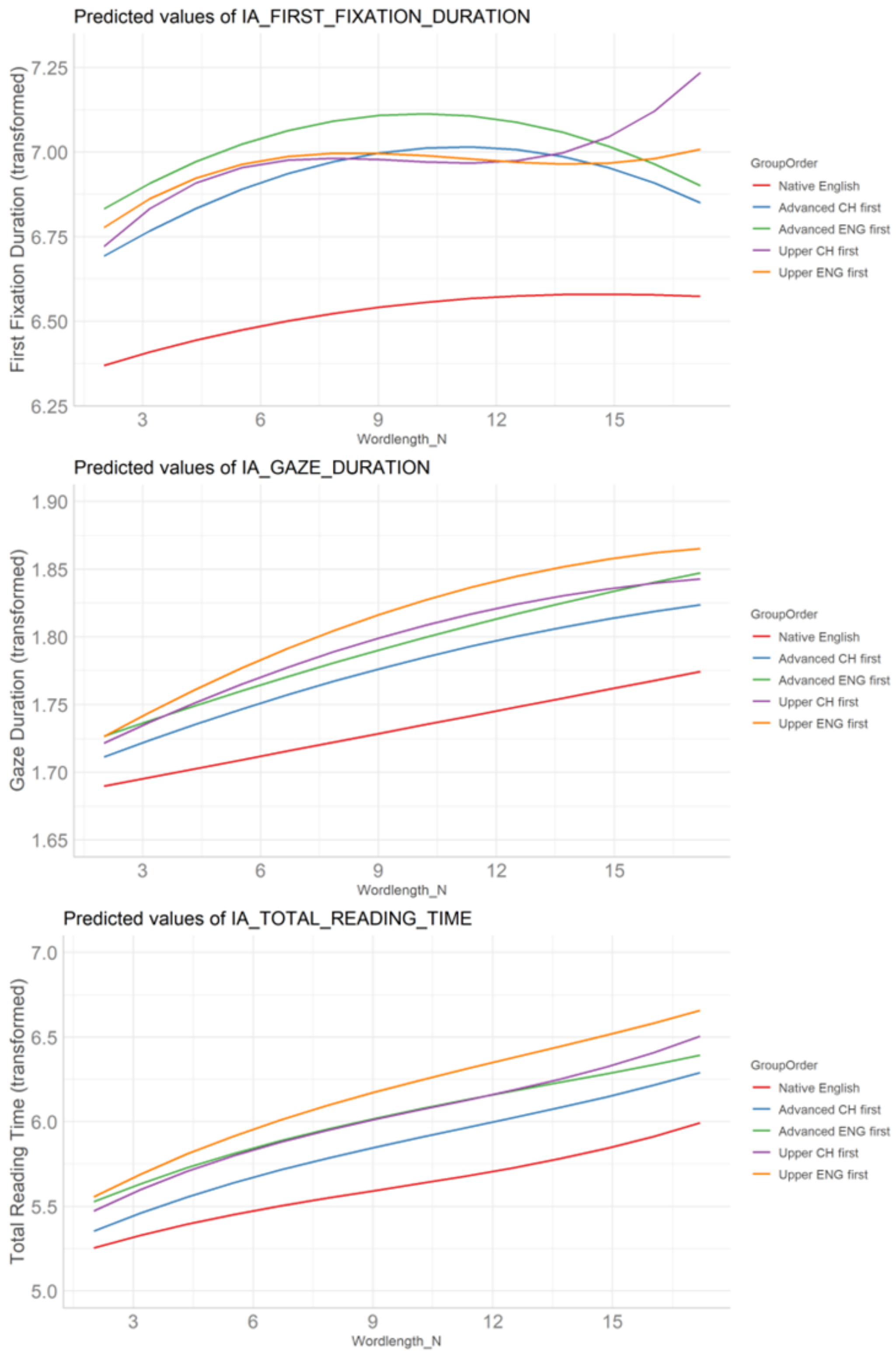
Beyond the effects of word and story sequencing, our study examined the influence of word characteristics, specifically focusing on word frequency and length — two of the most recurrent factors identified in word recognition research. Commonly encountered words are recognised more swiftly than their less frequent counterparts, and concisely constructed words are processed more rapidly than longer ones.

7.2.1 Length of the Word N

The plot in Figure 37 combines the three plots presenting the relationships between the length of the currently fixated word and the First Fixation Durations, Gaze Duration and Total Reading Time (after power transformation) when reading English.

Figure 37

Plots of the effect of the length of the currently fixated word N on first fixation durations, gaze duration, and total reading time on word N for all three groups



Firstly, in all three plots, the lines indicating the durations of the native readers are the shortest, which means that the native group, reading in their L1, needs the shortest time in reading at word level.

Second, the lines of the Advanced group remain below the lines of the Upper Intermediate group in gaze durations and total reading time, suggesting that participants in the Advanced group had shorter gaze durations than those in the Upper Intermediate group.

Thirdly, the modelling results show that the Wordlength_N is a statistically significant and positive predictor of all three eye movement measures for all three groups: the longer the currently fixated word is, the longer all fixation durations become. Starting from the early measure, first fixation durations, to the later measures gaze duration and total reading time, we can see significant influence of the word length on all three groups of participants. More specifically, the first fixation durations of the Advanced group who started with English (the green line) are longer than the first fixation durations of the Upper Intermediate group (the purple line and the orange line) regardless of reading order when the word length is shorter than 9 letters. But, as the word length becomes longer than 9 letters, we can see a clear declining trend of the first fixation durations made by the Advanced group, regardless of reading order, i.e., the first fixation durations become shorter as the word gets longer than 9 letters. However, the first fixation durations of the Upper Intermediate groups show an increasing trend, i.e., they become longer, especially for participants in the Upper Intermediate group who had read Chinese first.

In other words, L2 readers who are more proficient needed less time on all the word-level reading processes, including automatic word recognition and lexical access (indicated by first fixation durations). Moreover, their first fixation durations showed a non-linear relation with words shorter than 9 letters showing the expected positive relation between word length and first fixation duration, and words longer than 9 letters showing the inverse relation with longer words triggering shorter first fixation durations. The Upper Intermediate group displayed generally consistent relations, i.e., the longer the words are, the longer the first fixation durations get.

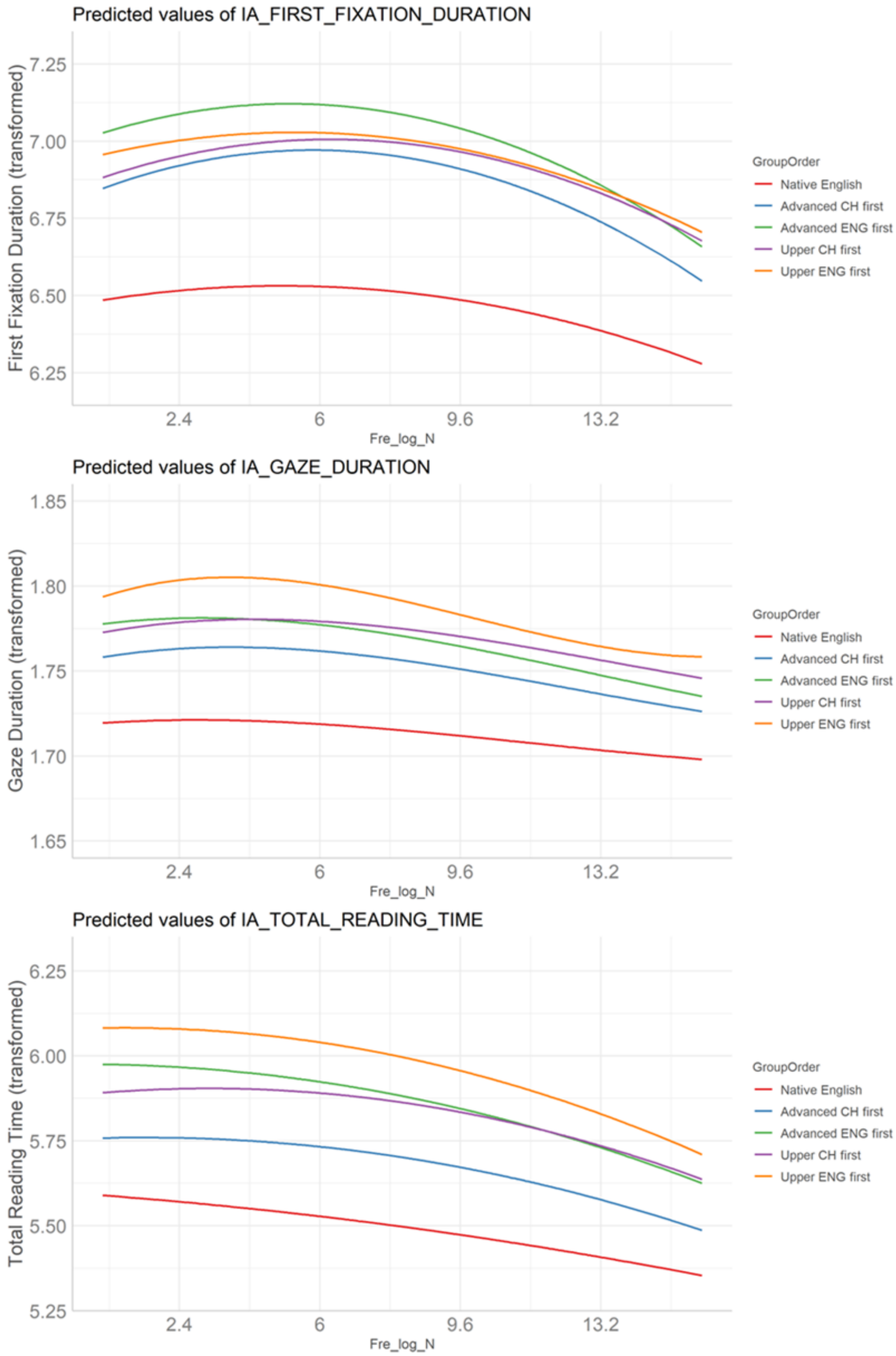
The similarity between the values for gaze duration and total reading time of the Advanced group who read English first and the Upper Intermediate group who read Chinese texts first is remarkable (see the blue line and the purple line in the bottom two plots in Figure 37). This finding suggests that letting less proficient readers access the content in the L1 first, allows them to read in the L2 in a fashion that resembles much more advanced learners.

7.2.2 Frequency of the Word N

As was the case for the effect of the length of the currently fixated word on fixation durations on that word, the frequency of the target word N is also statistically significant in predicting the variances of the First Fixation Durations, Gaze Duration and Total Reading Time on the target word for all three groups of participants. In Figure 38, we display the modelling results for the relationships between the frequency of the currently fixated word and how the frequency of that word helps to predict the variances of First Fixation Duration, Gaze Duration and Total Reading Time for the three groups of participants.

Figure 38

Plots of the effect of the frequency of the currently fixated word N on first fixation durations, gaze duration, and total reading time on word N for all three groups



The trends of all three groups share a general pattern: as the frequency of the word increases, the fixation duration on the word decreases, both for Chinese L2 readers and for English L1 readers. More specifically, gaze duration and total reading time of the Advanced group are shorter than those of the Upper Intermediate group. As before, we observe a strong similarity in the gaze durations and total reading time of the Advanced group who read English first, and the Upper Intermediate group which read Chinese first. That is, with the help of reading Chinese first, the gaze durations and total reading time of the Upper Intermediate group started to show the same level of frequency effect of the current word on the gaze durations and total reading time. This suggests that the prior exposure to Chinese text may have harmonised the reading patterns of the Upper Intermediate group, enabling them to respond to the frequency of words in a manner that is more uniform and predictable in terms of gaze durations and total reading time.

However, and a bit surprisingly, participants in the Advanced group who read English first showed the longest first fixation durations. Also, the difference between the first fixation durations of the Advanced group in both reading orders is larger than that of the Upper Intermediate group: reading Chinese texts with similar content first significantly helped to reduce the first fixation durations for the Advanced group but led to less difference between the first fixation durations of the Intermediate group.

7.3 The Effects of the Previous Word N-1

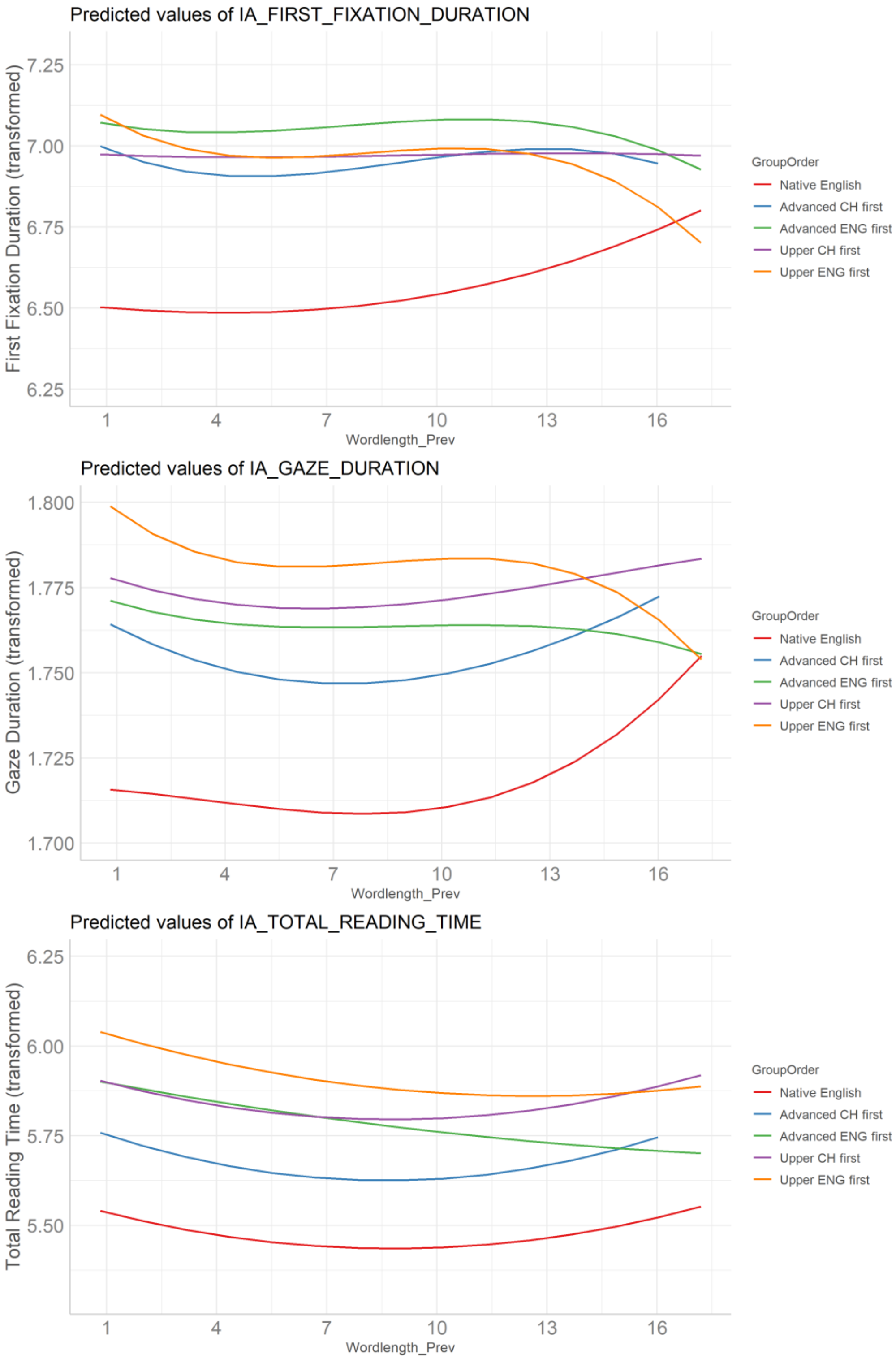
Next, we will focus on parafoveal processing which captures the effect of the preceding word N-1 on the durations of the currently fixated word N when reading.

7.3.1 Length of the Previous Word N-1

The plots in Figure 39 present how the length of the previous words correlates with the three different fixation durations. The primary findings of this study are fivefold and will be detailed as follows.

Figure 39

Plots of the effect of length of the previous word N-1 on first fixation durations, gaze duration, and total reading time for all three groups



Firstly, across all three measures, the native group had the shortest First Fixation Durations, Gaze Durations and Total Reading Time: they were the fastest on all measures which cover both early and late stage of reading processing.

Secondly, when we zoom in on first fixation durations, we see that the length of the previous word has the weakest influence on the first fixation durations of the currently fixated word for the Upper Intermediate group who read Chinese first. However, when the Upper Intermediate group read English first, they showed greater variance in first fixation duration. This, too, supports our view that reading similar content in their L1 optimised reading in L2 for readers of lower proficiency.

Thirdly, there is a notable difference between the Chinese groups and native English speakers in terms of their first fixation durations on a word and gaze durations. For native readers, the length of the word they fixated influences the time they spend on the next word: longer previous words lead to longer first fixation and gaze durations on the current word. This pattern is also seen when the Advanced group starts with Chinese texts (as indicated by the blue line). This suggests that reading in Chinese first aids the Advanced group in mirroring the native group's reading pattern concerning how the length of the previous word N-1 affects gaze durations on the current word, with the Advanced group's behaviour more closely resembling that of native readers. In contrast, the Upper Intermediate group exhibits a reverse trend: their first fixation and gaze durations on the current word shorten as the length of the previous word N-1 increases. However, when the Upper Intermediate group reads English as their second language first, they display the opposite pattern.

The fourth interesting result is that in gaze durations, the Chinese readers who read English first (in green) start to show a pattern that resembles the native readers: as the length of the previous words increases beyond 10 letters, the gaze durations increase. However, the gaze durations of the Chinese readers who read English first, regardless of proficiency level, showed a negative relationship with the length of the previous word N-1 when the length gets longer than 10 letters. Again, reading Chinese first helped the Advanced group to behave more like the native group in terms of the effect of the length of the preceding word.

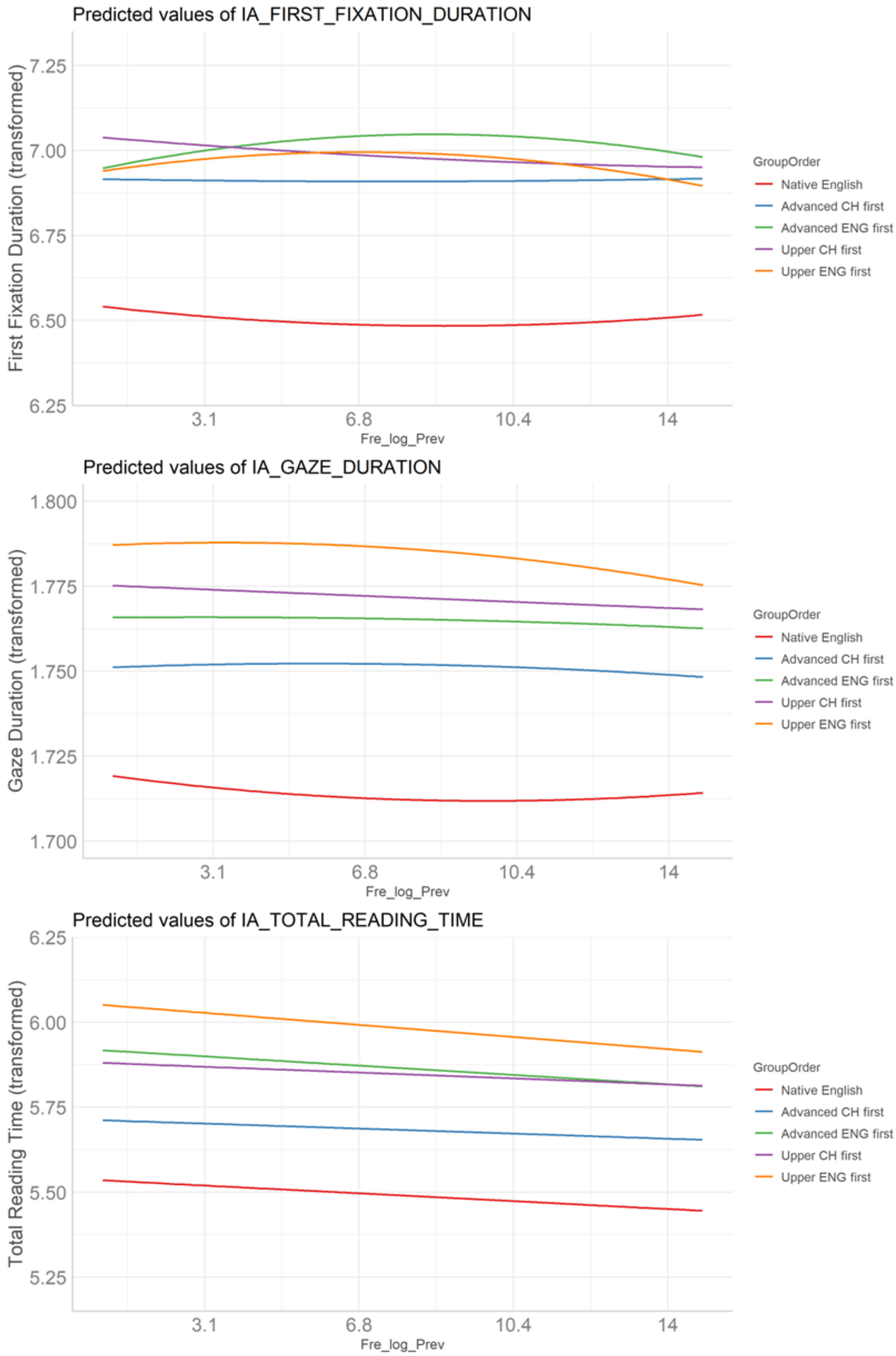
The last finding is that the differences among the three groups become smaller in total reading time as a measure of the initial retrieval and subsequent integration of a word: both Chinese groups who read English with prior experience of reading Chinese texts, show a pattern like the native group. This means that when it comes to the late measure, no clear difference can be found among the three groups if the two groups of Chinese participants read Chinese first.

7.3.2 Frequency of the Previous Word N-1

Apart from the length of the previous words N-1, the influence of the frequency of N-1 also appeared statistically significant. As the model results indicate, the significant influence of Fre_log_Prev was found to predict the variance of the first fixation duration, gaze duration and total reading time for all three groups.

Figure 40

Plots of the frequency of the previous word N-1 on first fixation durations, gaze duration, and total reading time on word N for all three groups



In all panels in Figure 40, the first fixation durations, the gaze durations and the total reading time of the native group are the shortest. The Chinese groups who read English first (green) differ considerably from the native group in terms of first fixation durations but the difference among the three groups is smaller for gaze duration and total reading time.

The bottom panel of Figure 40 shows the relationships between the frequency of the previous words and the total reading time on the currently fixated word N. Even though the three groups behaved differently for first fixation durations (top panel) and gaze duration (mid panel), all three groups showed a declining trend in total reading time as the frequency of the previous word N-1 increases. When it comes to late measures, which are more influenced by contextual, syntactic, or discourse-level properties of what is being read than by purely lexical factors, both Chinese groups tended to show a similar pattern with the native group.

7.3.3 An interim summary

In the preceding sections, 7.3.1 and 7.3.2, we observed that the characteristics of the preceding word, particularly its length and frequency, affect the duration of fixations on the current word. To further elucidate this finding, we shall re-examine the E-Z Reader model. This model of eye movement control during reading is predicated on the concept of strictly sequential shifts of attention from one word to another, contingent upon lexical access (Reichle et al., 2003). This model does permit a restricted degree of distributed word processing across fixations. This is because it posits that saccade programs (signals sent to the oculomotor system to initiate a saccade towards the next unrecognised word in the text) are activated by an early phase of lexical access. As a result, the eyes might shift either before or following the completion of lexical access. However, this distributed processing is constrained, as the initiation of saccade programs is connected to sequential lexical processing. This central principle of the E-Z model helps explain the impact of the preceding word on the fixation duration of the currently fixated word. It posits that the lexical processing of word N-1 must be completed before the processing of word N can start. However, the actual saccade and lexical processing may not be synchronised. If the eyes move from word N-1 to word N before the full lexical processing of word N-1 is completed, this could influence the duration of fixation on word N (Schroyens et al., 1999). In this scenario, the duration of fixations on word N is thought to demonstrate a spill-over effect from the unfinished processing of word N-1. It is more probable that low-frequency words will undergo this incomplete processing.

This framework is particularly relevant to our findings. It helps explain how the processing of the previous word (word N-1) influences fixation duration on the current word (word N). According to the model, in reading, averagely speaking, a fixation on a long word N-1 will be further away from word N. Consequently, the preview advantage for word N will be diminished because of a decline in visual acuity and the resulting lateral inhibitions. As a result, the length of word N-1 forecasts the duration of fixation on word N. We found a clear effect of the length of word N-1 on first fixation durations on word N for the native group: as the length of the previous word gets longer, the first fixation durations on the currently fixated word get longer accordingly. Thus, our findings align with the E-Z Reader model's assumptions, illustrating the interplay between sequential processing and eye movement dynamics in reading. However, we did not find the same effect on either Chinese group when reading English. The reduced effect might also stem from differences in visual processing and acuity. If the Chinese readers are not as accustomed to the alphabetic script and its spacing as native English speakers, their ability to gain preview benefits from parafoveal vision might be reduced.

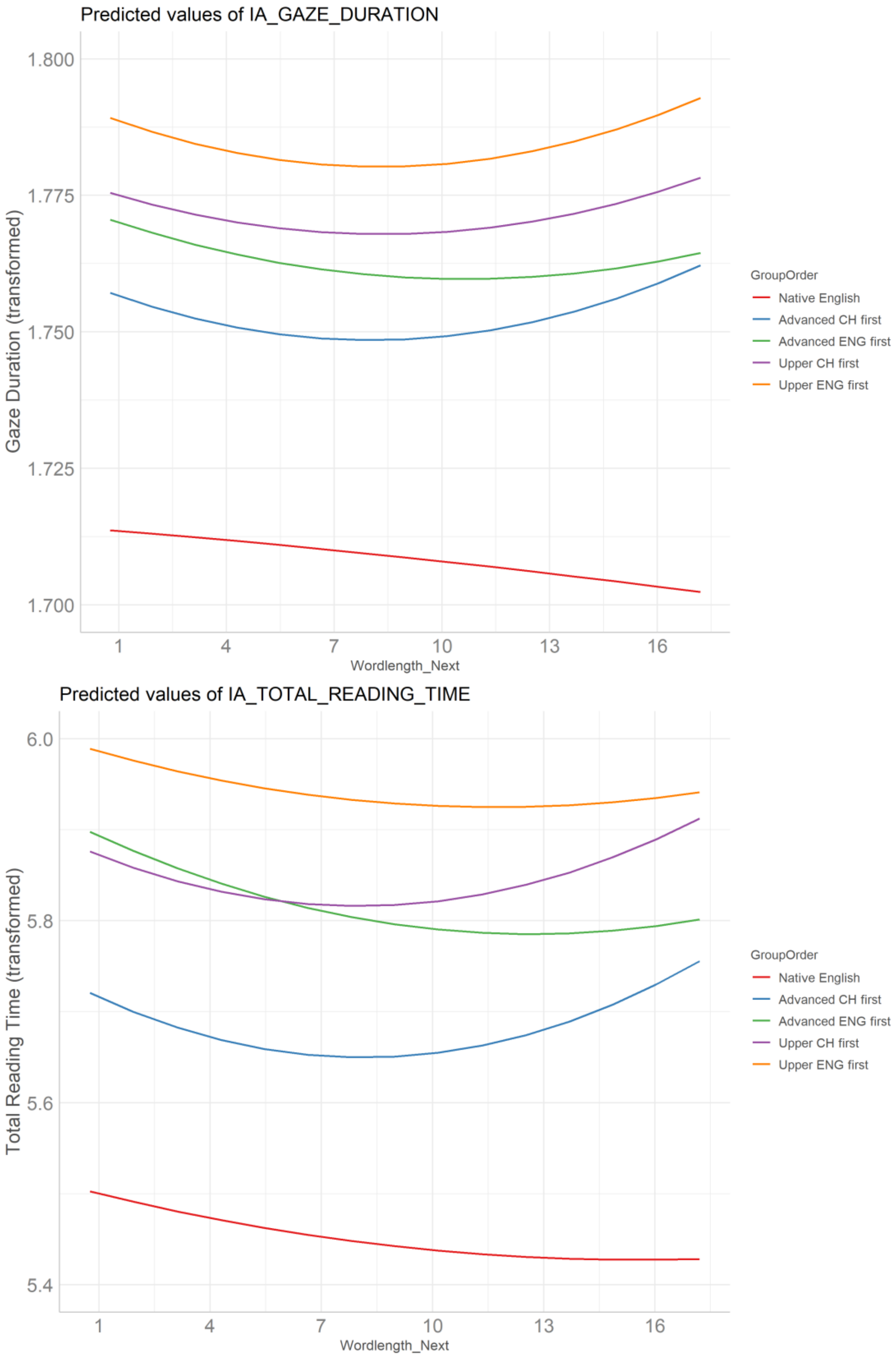
7.4 The Effects of the Next Word N+1

7.4.1 Length of the Next Word N+1

As in previous research on L1, we found a statistically significant influence of the length of the next word N+1 on the durations of the currently fixated word N. In Figure 41, we present the combined result of the relationships between Wordlength_Next and First Fixation Durations, Gaze Duration, and Total Reading Time respectively.

Figure 41

Plots of the length of the next word N+1 on gaze durations, and total reading time on word N for all three groups



In the top panel in Figure 41 on the length of the next word and its relationship with gaze durations, we see that the native group, again, has the shortest gaze durations among the three groups and the relationship is linear. Both Chinese groups show a non-linear relationship between the length of the upcoming word and the gaze durations on the currently fixated word. This suggests that the length of the next word N+1 and it is influence on the gaze durations and total reading time to both Chinese groups are not consistent, but sensitive to the change of the length. For all Chinese readers, regardless of proficiency level and reading order, we see that when the length of the next work is shorter than 7 letters, the Chinese groups have a similar pattern as the native group, which is shorter gaze durations on the currently fixated word when the next word is shorter. But when the upcoming word has more than 7 letters, the gaze durations on the currently fixated word of both Chinese groups get longer. This means that, while Chinese readers are fine with shorter upcoming words, they struggle with longer upcoming words. This is not surprising because Chinese mostly has 2-character words which are visually short.

From a processing standpoint, the magnitude of the perceptual span and the length of words within the current perceptual span are crucial in the development of parafoveal-on-foveal effects. Moreover, the asymmetric shape of the perceptual span (McConkie & Rayner, 1975) appears to be subject to modulation by foveal load. We will discuss this further in the upcoming sections.

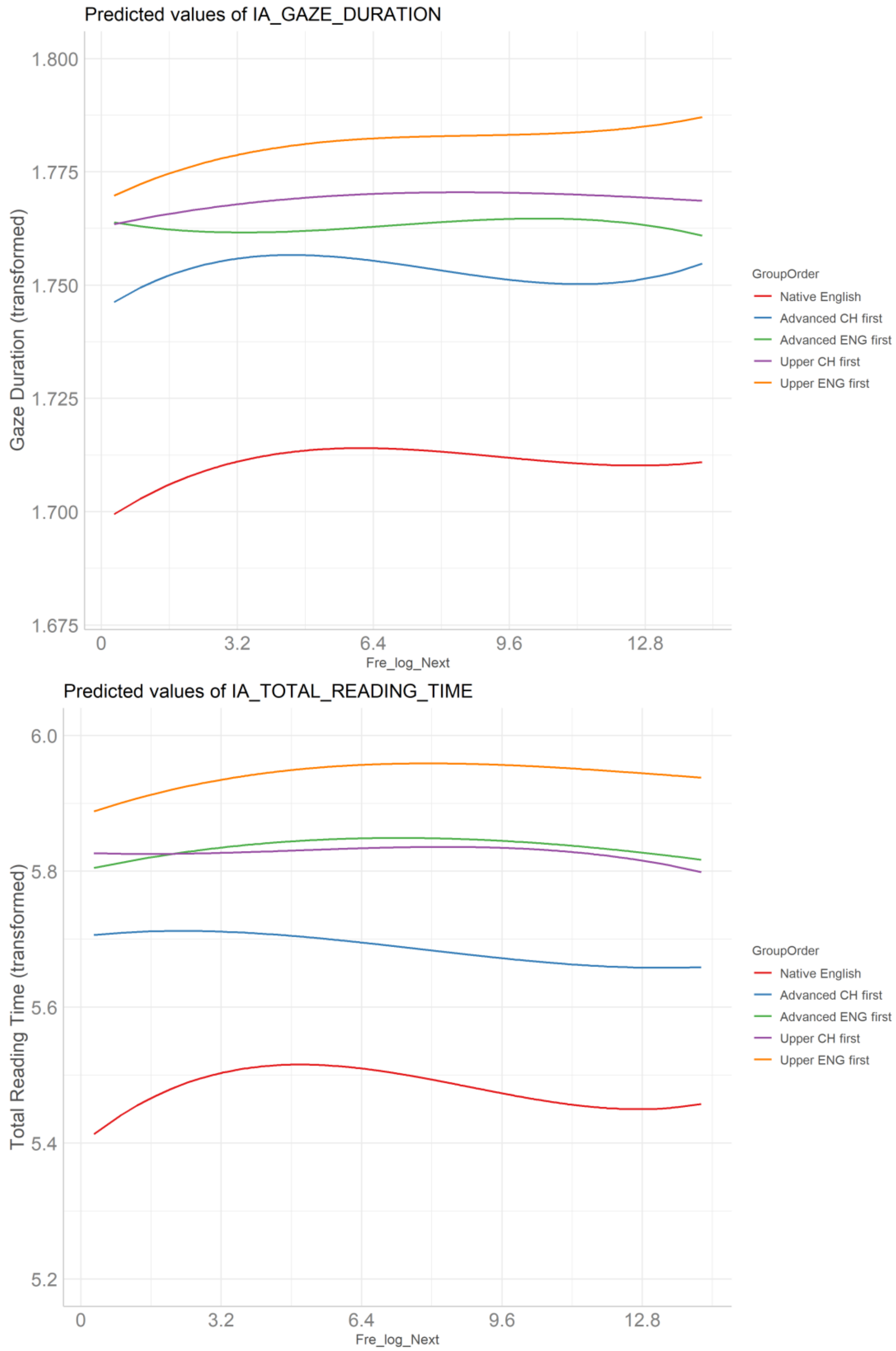
7.4.2 Frequency of the Next Word N+1

Apart from the length of the next word N+1, the influence of the frequency of N+1 was also found to be statistically significant. The relationships between the frequency of the next word and the gaze duration and total reading time on the currently fixated word in reading English is summarised in Figure 42.

There were only significant non-linear relationships for the native group (red) between log frequency of the next word and gaze durations after power transformation on the currently fixated word and the Advanced group when they read English texts first. For native English speakers, the frequency of the upcoming word seems to play a role in how long they gaze at the current word. This could indicate that they are able to anticipate or predict upcoming words based on their frequency, adjusting their reading pace accordingly. A similar pattern in the Advanced group who read English texts first suggests that higher proficiency in English may lead to more native-like reading behaviours, including the use of word frequency for word prediction. The fact that these relationships are non-linear after a power transformation implies a complex interaction between word frequency and gaze duration. It is not a simple case of more frequent words always leading to shorter or longer gaze durations, but rather a more intricate relationship that could be influenced by various factors such as context, reader expectations, and familiarity with the text. However, the native group (red) and the Advanced group (blue) who read Chinese first share a similar pattern. The fact that the Advanced group, when reading Chinese texts first, aligns their reading patterns with those of native English speakers could suggest that prior exposure to their L1 facilitates their reading in their L2 in a manner more akin to native English speakers.

Figure 42

Plots of the frequency of the next word N+1 on gaze durations, and total reading time on word N for all three groups



7.5 Discussion

The aim of the English reading experiment was to investigate the influence of L2 proficiency level and exposure on the eye-movements (i.e., fixations durations) of L2 English reading by Chinese readers. A range of empirical evidence for both foveal and parafoveal processing has been reported and comparisons between two Chinese groups with different L2 proficiency levels and exposure have been made.

Word Story Order. This investigation into reading behaviours across different languages and proficiency levels reveals multifaceted insights into the cognitive processes of reading. Our findings particularly underscore the impact of Scaled_Word_Story_Order on reading efficiency among various groups.

Regarding the differences between the effects of word order, we can glean two primary takeaways from our results. Firstly, similar to native English speakers, advanced Chinese participants with higher L2 proficiency and exposure also showed facilitating effects of word order in the early word recognition stage. In considering the English reading study as an entire process, both native and advanced non-native speakers demonstrated shorter first fixation durations as they progressed through the reading material. This pattern indicates an increase in reading speed at the initial word recognition stage, suggesting improved lexical access as a result of increased exposure to the language.

The advanced non-native speakers' convergence toward native-like reading patterns, particularly after reading English, supports the hypothesis that enhanced L2 proficiency and extensive exposure lead to more efficient word recognition and decoding. Meanwhile, native speakers' decreasing fixation durations as they approach the end of the stories may be attributed to cognitive priming and an overall increase in processing efficiency.

However, the second takeaway highlights a contrast: the Upper Intermediate group only manifested the effects of word order on their First Fixation Duration when they had previously read similar texts in their native language, Chinese. This implies that for less skilled L2 readers, the familiarity with content in their L1 provides a scaffold that enhances their word recognition speed in L2. Such an advantage suggests a transfer of processing efficiency from L1 to L2, emphasising the role of prior knowledge and linguistic structure familiarity in reading.

Moreover, while the Scaled_Word_Story_Order became statistically significant for later eye-movement measures among the Chinese groups, it is noteworthy that the differences between these groups grew more pronounced from the initial fixation to the total reading time. The Advanced group, when starting with Chinese texts, displayed the shortest total reading times, which could reflect an initial advantage of reading in one's native language.

These patterns reveal intricate dynamics between language proficiency, exposure, and text sequencing, which shape the reading experience. Participants with lower L2 proficiency benefit from the prior reading in their native language, likely due to the cognitive load reduction and the utilisation of established semantic and syntactic frameworks.

Collectively, the results contribute to a nuanced understanding of the interaction between reader characteristics, text structure, and task demands. They suggest that reading is not merely a passive reception of text but a complex cognitive endeavour that is dynamically influenced by the reader's language background, the order of text presentation, and the cumulative exposure to the language. Future research may delve into how these factors interact on a broader scale and how they influence learning and fluency in multilingual contexts.

Properties of the Currently Fixated Word. Results regarding the effect of length and frequency of the currently fixated word on the three main fixation-related variables are consistent with models like E-Z Reader (Reichle et al., 1998). The theoretical assumption of the model can be used to examine possible relationships among three important predictors of reading ability (i.e., orthographic knowledge, phonological processing skill, and sentence comprehension) and various eye-movement measures of reading fluency (e.g., fixation durations). In our study we found that in Total Reading Time, the Advanced group with higher L2 proficiency and exposure were faster, with shorter fixation durations that were closer in value to those of the native English readers. For native English readers, their knowledge of word frequency is gained through implicit learning via repeated exposure to words with high frequency which strengthens the lexical representation, leading them to reach threshold sooner than for low frequency words. Thus, less processing time is needed for high frequency words than low frequency words. However, Chinese participants in both groups had lower exposure to English resulting in knowledge that is less well correlated with frequency of occurrence and hence slower/longer lexical access. Whitford and Titone (2012b) reported that bilinguals with higher levels of current L2 exposure showed larger L2 frequency effects than did bilinguals with lower level of L2 exposure, which suggested increased L2 experience modifies the earliest stages of L1 lexical access. However, our results do not support this conclusion as we did not find distinct patterns regarding L2 exposure and frequency effects (i.e., between the frequency of the currently fixated word N and the First Fixation Duration, Gaze Duration and Total Reading Time on it, see Figure 38.

With regards to the effect of the length of the currently fixated word on early lexical access, we found a stronger influence of word length for the Chinese group with lower L2 proficiency and exposure. More specifically, for readers with lower L2 proficiency and exposure, first fixation durations tended to be more sensitive to the length of the word they fixated than for the group with higher L2 proficiency and exposure, as well as for the native group. For the native group, we observe a nearly linear positive relation, while for both L2 groups, with lower proficiency level and exposure, the relations between the length of the currently fixated word and the first fixation durations become more varied.

Properties of the Neighbouring Words. We found strong effects of the length and frequency of the preceding word on the fixation durations on the currently fixated word. For the native group as skilled readers of English, there was clear evidence of the effect of the length of the previous word N-1 on the currently fixated word N in terms of early access (indicated by first fixation durations and gaze durations). Our result is in line with the previous findings reported by Kliegl et al. (2006). A possible way to interpret is that if the processing effort of the preceding word N-1 is high, it becomes more likely that processing of N-1 is ongoing when a fixation is made on word N. Another possible explanation for the effect of length of the preceding word on the currently fixated word is the limit of visual acuity. As the preceding word is longer with more letters, it is likely that a fixation on that long word N-1 will be further away from word N, and consequently, the preview benefit for word N will be reduced due to the drop-off in visual acuity and associated lateral inhibition. Therefore, the length of word

N-1 predicts the duration of fixation on word N. More specifically, the longer the previous word N-1, the longer the first fixation durations on the currently fixated word. In contrast with the clear effect of the length of the previous word N-1 on the first fixation durations and gaze durations on the currently fixated word found for native readers of English, the effect of the length of the previous word was weaker if not opposite in both Chinese groups. One possible reason for this is that in Chinese, most words are two-character words which weakens the effect of the length of the preceding word on the durations on the currently fixated word due to limits of visual acuity, and L2 learners of English with Chinese as L1 have not yet developed the ability to capitalise on the previous word. We will investigate this further in Chapters 8-11.

Our results regarding the spill-over effects from word N-1 on word N for frequency are similar to those found in English reading (Pollatsek et al., 2008; Rayner et al., 2004; Rayner et al., 2006; White, 2008) and German reading (Kliegl et al., 2004; Kliegl et al., 2006). In other words, as the length of the previous word gets longer, the gaze durations on the currently fixated word get shorter for Chinese readers with low proficiency and exposure. What is new in this study is that we found a similar pattern for L2, at least if both Chinese groups read English texts with prior experience of reading Chinese as L1.

The foveal-load hypothesis proposed by Henderson and Ferreira (1990) assumes that the perceptual span decreases with the difficulty of the foveal word, such as when fixating low-frequency words (Inhoff & Rayner, 1986; Rayner & Pollatsek, 1987). The assumption is that a significant amount of processing allocated to word N-1 reduces the possibility of previewing word N. This diminishes the preview benefit for the word N, leading to the prediction that low-frequency words N-1 should be followed by increased fixations on N. From the perspective of literature on second language acquisition, it is reasonable to assume that L2 readers have a narrower perceptual span than L1 readers (Rayner, 1986). According to accounts based on foveal load (Henderson & Ferreira, 1990), a lower level of automaticity in word recognition (Favreau & Segalowitz, 1982) may result in increased processing costs and, consequently, a reduced perceptual span during L2 reading. However, reading texts with similar content in their L1 before attempting to read them in their L2 appears to have annulled this effect, yielding a very similar ocular behaviour in L2 readers of both proficiency levels as in L1 readers.

In short, what we found about the effect of the preceding word led to two new findings. Firstly, in first fixation durations, as L2 readers of English, Chinese participants in both groups showed weaker effects of the length of the previous word on the first fixation durations on the currently fixated word. Secondly, reading Chinese texts as L1 with similar content helped both Chinese groups show a similar pattern with the native group regarding the effect of the length of the previous word on gaze durations.

In our study, length, and frequency of the next word N+1 were also found important to predict the variance of the gaze durations and total reading time in reading English texts for all three groups. With regards to the length of the upcoming word N+1, we found salient negative linear relations for the native group: as the length of the next word gets longer, their gaze durations and total reading time on this word gets shorter. However, the relations between the length of the next word and the gaze durations and total reading time on the currently fixated word was not linear for L2 readers. For them, when the word length of the upcoming word exceeds 8 letters, the pattern started to show the opposite trend meaning that the gaze durations and total reading time on the currently fixed word became longer. It is interesting to find a non-linear relation here with Chinese participants because it was not reported in the previous study. It suggests that Chinese readers, who are used to reading 2-character words, struggle to accommodate their parafoveal span to capture longer distances.

Chapter 8: The Chinese Reading Study - First Fixation Duration

In Chapter 4, we focused on the first fixation durations of Chinese readers of English as a second language. We compared the first fixation durations of two groups of Chinese learners of English based on their L2 proficiency and exposure and found that the two groups of Chinese participants exhibited significant differences in first fixation durations between them and compared with the native readers group. Moreover, we found that the first fixation durations of Chinese participants as L2 readers on the currently fixated word N were modulated and affected by properties of both the currently fixated word and neighbouring words.

This chapter aims to analyse the first fixation durations of Chinese participants when reading Chinese as L1 to examine whether these differences relate to reading Chinese in general, or properties of the individual readers. Recall that we aim to explore the interplay of the L2 reading patterns of the L1 reading patterns, therefore in analysing the L1 reading patterns, we kept the grouping method in L1 reading, i.e., based on their L2 proficiency and L2 exposure in English. Thus, Chinese participants were grouped into the Advanced group and the Upper Intermediate group as in L2 reading study and analysis. The research questions in this chapter are as follows:

1) Do the Advanced group and the Upper Intermediate group of Chinese L1 readers have different first fixation durations?

2) What are the word level and text level properties that modulate the first fixation durations of two Chinese groups in different orders when reading Chinese as L1?

3) Are these word-level and text-level properties the same or different from the properties we found significant in the first fixation durations of reading English as L2?

This chapter begins with the findings of a descriptive analysis comparing the first fixation durations of the two Chinese participant groups across reading order conditions. Afterwards, the results and figures of the results of statistical modelling will be presented and discussed. This chapter will conclude with a summary and comparison of the first fixation durations of two Chinese groups when reading Chinese and English (resuming the main results presented in Chapter 4).

8.1 Preliminary Data Analysis

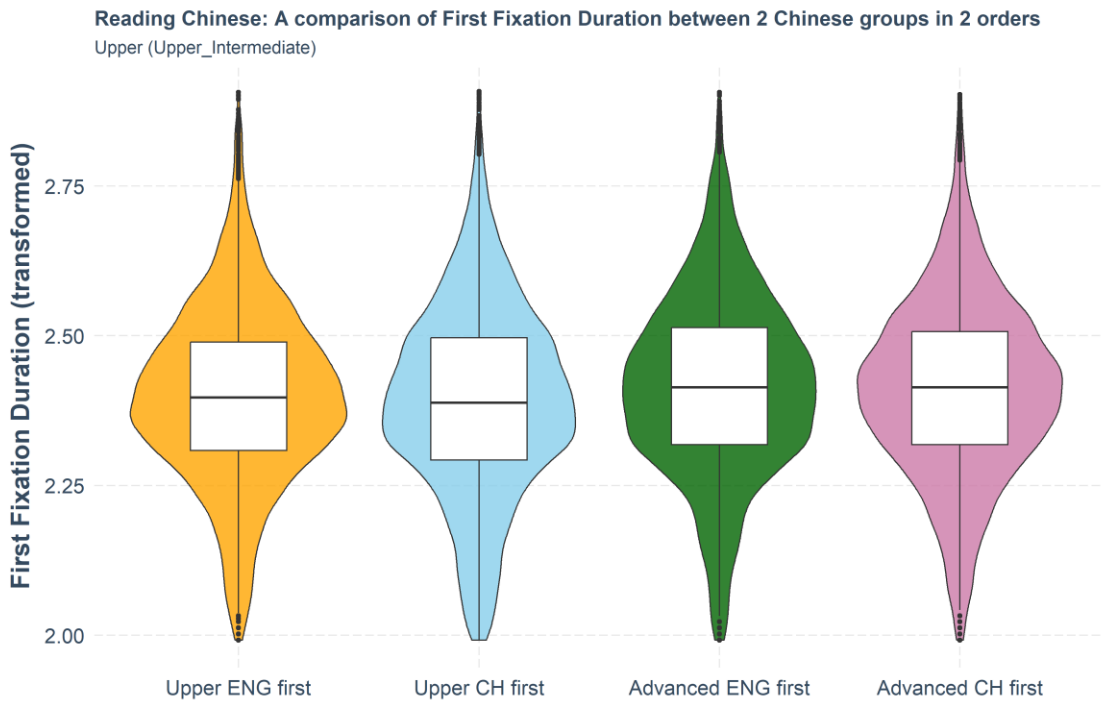
Recall that in the experiment design section, we explained that the Chinese participants were assigned to two reading orders. 19 Chinese participants started with the Chinese reading study, followed by the English reading study. The remaining 20 Chinese participants, however, began with the English reading study then reading Chinese texts.

In our examination of English reading from Chapter 4 to Chapter 7, we delved into a detailed analysis of first fixation durations, gaze durations, and total reading time among two distinct Chinese groups, each with varying degrees of L2 language proficiency, exposure and following different reading orders. This investigation led us to three principal conclusions concerning the first fixation durations in English reading, as expounded in Chapter 4. Firstly, we observed that the Chinese Advanced group experienced a distinct advantage when they had previously read similar Chinese stories before embarking on English texts. This advantageous effect manifested itself in the form of a statistically significant reduction in the mean duration of first fixation. The effect was also significant in the Upper Intermediate group, indicating that reading similar content in Chinese beforehand also notably improved their word recognition.

Next, we will first compare how the reading orders influenced the first fixation durations of Chinese participants in the Chinese reading study. To visualise the differences, four violin plots (Figure 43) are created to present how the first fixation durations of the two Chinese groups were influenced by different reading orders when reading Chinese as L1.

Figure 43

Violin plots of first fixation durations of two Chinese groups in reading Chinese



The x-axis displays two Chinese groups alongside two different orders which represent reading in Chinese and English texts. The y-axis represents the values of First Fixation Duration (values are transformed). *Upper ENG first* means the first fixation durations of participants in the Upper Intermediate group who read English first. *Upper CH first* represents the first fixation durations of participants in the Upper Intermediate group who read Chinese first. Similarly, *Advanced ENG first* and *Advanced CH first* describe the first fixation durations for the Advanced group, also reflecting the order in which they read the languages.

From Figure 43, it is observed that the Upper Intermediate group's average first fixation duration was longer when they read English text first (orange violin) compared to starting with Chinese text (blue violin). Additionally, Figure 43 shows that the Advanced group took longer to recognise words when they read English text first (shown by the green violin) compared to when they read Chinese text first (shown by the pink violin). This means that after reading English texts with similar content before they read the Chinese texts, their mean value of first fixation durations on the currently fixated word was greater than in the other reading order. In other words, reading English texts first did not statistically significantly help readers in both the Upper Intermediate group and the Advanced group spend less time reading Chinese, but in fact made their general first fixation durations longer. In summary, for both groups, reading English texts first actually led to longer word recognition times in Chinese, as indicated by extended first fixation durations. A more detailed report with key features about the distributions of the first fixation durations of two groups in two orders can be found in Table 12.

Table 12

First fixation durations of both Chinese groups in both reading orders in reading Chinese

Group	Mean	Median	SD	MAD
Upper ENG first	2.399	2.397	0.148	0.132
Upper CH first	2.391	2.388	0.162	0.150
Advanced ENG first	2.416	2.414	0.154	0.143
Advanced CH first	2.411	2.414	0.151	0.141

To test whether the difference between the Upper Intermediate group and the Advanced group in different reading orders is statistically significant, we ran two z-tests to test and compare the first fixation durations of the Upper Intermediate group and the Advanced group in two reading orders. First, a z-test was conducted comparing the mean for the first fixation durations of participants in the Upper Intermediate group who read English texts first (M = 2.399, SD = 0.148) to the first fixation durations of participants in the Upper Intermediate who read Chinese texts first (M = 2.391, SD = 0.162). The result was statistically significant (z = 3.247, p = 0.001166, two-tailed). The participants who read English text first showed longer first fixation durations in reading Chinese than the ones who read Chinese first. Similarly, a z-test for mean values was conducted to compare the first fixation durations in reading Chinese for participants in the Advanced group who read English texts first (M = 2.416, SD = 0.154) and who read Chinese texts first (M = 2.411, SD = 0.151). The Advanced group who read English texts first showed longer mean first fixation durations than those who read

Chinese first, but this difference was not statistically significant ($z = 1.8746$, $p = 0.06085$, two-tailed).

The z-test results lead to a key finding. The Upper Intermediate group, who are less proficient in their second language (L2), didn't have quicker word recognition in Chinese (their first language or L1) after reading English (L2) texts. In other words, reading in English first didn't help them recognise Chinese words faster. In fact, they took longer to recognise words in Chinese if they read English first, as seen in their first fixation durations. Remember, in the English reading study, this group showed slightly lower first fixation durations when they read Chinese texts first, but this wasn't a significant difference. Essentially, for the Upper Intermediate group, reading L2 English texts first negatively impacted their speed of recognising words in their L1 Chinese.

In the previous section 8.1, systematic comparisons were conducted to explore how different reading orders influence the first fixation durations of two proficiency groups of Chinese participants. Next, we will move to inferential statistics, where we will use mixed effects modelling as our main statistical tool to find what are the main predictors that are statistically significantly influencing the first fixation durations of two groups of Chinese participants in two reading orders.

8.2 Statistical Modelling the First Fixation Duration Data

The response variable first fixation durations (IA_FIRST_FIXATION_DURATI ON) was analysed using a Linear Mixed-Effects model. Models were fitted using the lmer function from the lme4 package (Version 1.1-26, Bates, Mächler, Bolker, & Wal ker, 2014) in the R Environment for Statistical Computing (Version 3.3.1).

We will examine how different properties of a currently fixated word N, as well as of the previous word N-1 and upcoming word N+1 (listed in

Table ***13***) affect the duration of the first fixations on that currently fixated word N with the data of Chinese participants reading Chinese. Again, order variable was used as a control variable which is consistent with other analyses.

As in the previous chapters, we focused on two types of properties as independent variables to predict the variance of the first fixation durations in reading Chinese. The word-level properties included the length and frequency of the currently fixated word N, the length and frequency of the previous word N-1, and the length and frequency of the next word N+1 and the order variable. Data preprocessing regarding the values of length and frequency of Chinese words can be found in Section 3.9.2.

Following the execution of various models and comparison based on their R^2 values, the model with the best overall fit was selected. The outcomes of this model will be displayed and illustrated in the forthcoming sections.

Table 13

A complete list of variables included in the most parsimonious model to predict the first fixation durations on word N in reading Chinese

Property Types	**Variable Names**	**Explanation**
Word-level Properties	Log_Freq_N	the frequency after logarithm of the current fixated word N
	Wordlength_Next	the length of the upcoming word, N+1
	Log_Freq_Prev	the frequency of the word left to the current fixated word, i.e., word N-1
Text-level Property	Scaled_Word_Story_Order	the combined order of a word in a story and the order of a story in the reading study

In Table 13, the two types of properties include word-level properties and properties at the text-level. The second column provides the names of variables used in the models. The Note column gives a description about the definition of the variable in the model. The rightmost column presents whether the variable is found statistically significant in the final (most parsimonious model after statistical comparison using anova test).

The specification of the final best model is:

```
IA_FIRST_FIXATION_DURATION_PowerT ~
    GroupOrder / (
        poly(Scaled_Word_Story_Order, 2) +
         Log_Freq_N +
         Wordlength_Next +
         poly(Log_Freq_Prev, 3)) +
    (1 | Participant_ID) +
    (1 | Story_ID) +
    (1 | Word_ID)
```

A complete report about the results of this model can be found in Appendix 8. The main findings in Appendix 8 include Estimates values of each variable at different levels, CI (Confidence Interval) and p values.

As the formula indicates, we ran linear mixed model allowing for non-linear relationships where needed (i.e., tested as significant) using polynomials. In our model, the polynomial Scaled_Word_Story_Order, Log_Freq_N and Log_Freq_Prev were found statistically significant. We also added GroupOrder as a predetermined group based on the statistically significant differences among groups tested in the preliminary data analysis in Section 8.1

The model's total explained variance R^2 is 0.11. It means that this model can predict 11% of variance in the first fixation durations based on the eye-movement data of two Chinese groups reading Chinese.

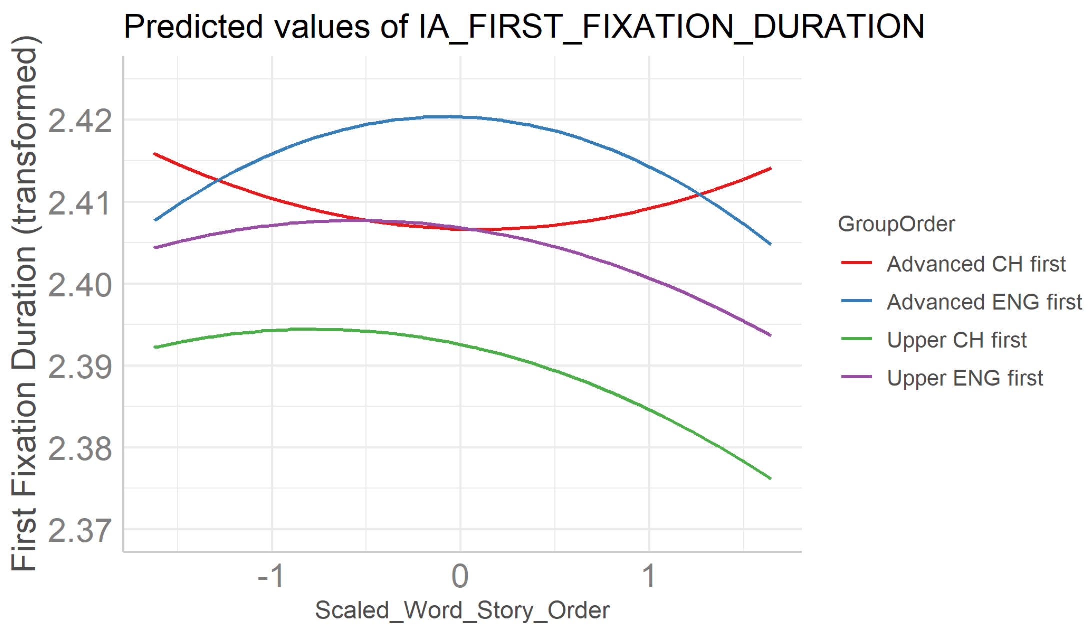
The next section lists all the fixed effects in the model that are statistically significant, as shown by the test results. We have also created visual representations of these results, which are shown in the upcoming figures. These visuals help demonstrate the differences between two groups of Chinese readers, categorised by their second language proficiency and the order in which they read in the Chinese reading study. The next section details all the significant fixed effects in the model, with statistics and figures showing differences between two groups of Chinese participants based on language proficiency and reading order.

8.2.1 The Order Effect

Remember that 19 Chinese participants began by reading texts in Chinese and then proceeded to read English texts. Conversely, another group of 20 Chinese participants started with English texts before moving on to Chinese texts. Here in Figure 44 we visualised the relations between first fixation durations of both Chinese groups with different orders in reading Chinese texts based on the model's prediction of the word position.

Figure 44

The effect of the Scaled_Word_Story_Order on the first fixation durations on word N for two Chinese groups in reading Chinese with different reading orders



The x-axis in the figure represents the word order. The greater the value, the later that word was read. The y-axis represents the first fixation durations. The pattern of the Advanced group who read Chinese first was indicated as the red line, and the Advanced group who read English first was shown as the blue line. The pattern of the Upper Intermediate group who read Chinese first was presented as the purple line and who read English first was shown as the line in green. Same colour-coding rules are shared in the following plots in this chapter and the following two chapters.

The Figure 44 reveals three interesting patterns of effect. Firstly, the first fixation durations of the Upper Intermediate group were shorter when reading Chinese texts first. Also, regardless of reading order, for the Upper Intermediate group, as a reader progresses through words and stories, the first fixation durations of the Upper Intermediate group in two conditions got shorter.

Second, for the Advanced group, we observed quite opposite patterns with two different reading orders. The general difference is that the first fixation durations of the Advanced group who read Chinese first were shorter than the first fixation durations of participants who read English first. Additionally, as indicated by the red line, the Advanced group's first fixation durations initially decreased when they started reading Chinese, but then increased towards the end of the Chinese reading experiment. Moreover, as indicated by the red line, when participants in the Advanced group started with Chinese, their first fixation duration initially got shorter, but it increased again towards the end of the Chinese reading experiment. However, with prior experience of reading English (the blue line), the Advanced group made longer first fixation durations when they read Chinese texts. Towards the end of the reading experiment, their fixation duration shortens. This finding is interesting and will be discussed further when we reported gaze duration and total reading time in reading Chinese.

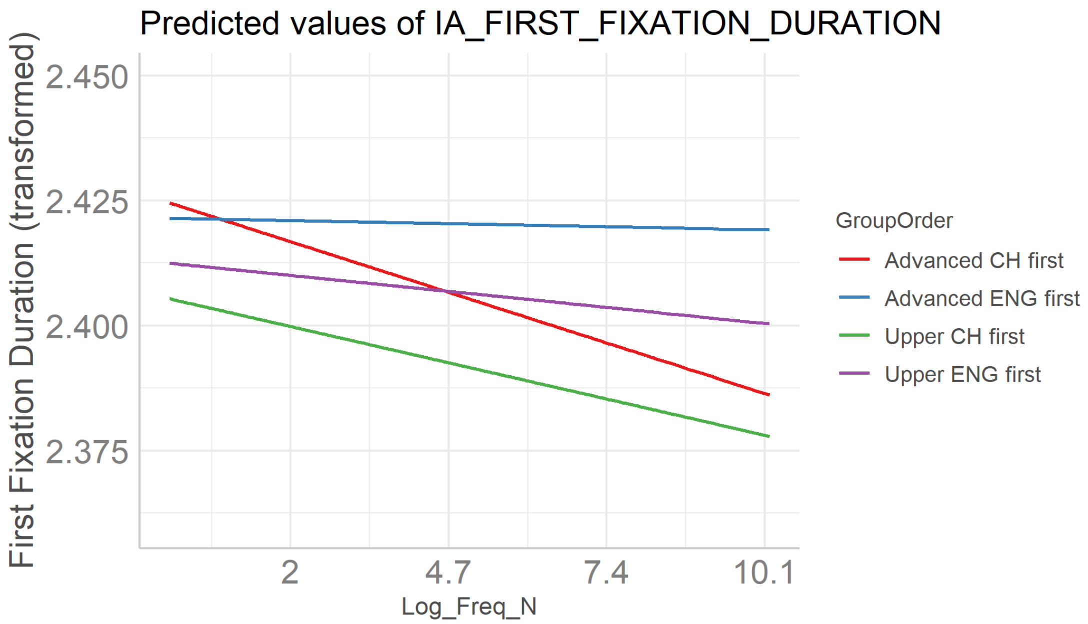
The third observation concerns the different patterns between the two proficiency groups when they both read Chinese first. The Upper Intermediate group (green), read with shorter fixations as they read more. However, for the Advanced group (red), the first fixation durations did not show a consistent declining trend.

8.2.2 The Effect of the Frequency of Word N

As shown in the results of the model, the frequency of the currently fixated word N was statistically significant predictor of the first fixation duration in reading Chinese for both Chinese groups of readers. Figure 45 displays the predicted first fixation durations for reading Chinese texts, based on the model's estimation of the frequency of the word currently being fixated on, denoted as N.

Figure 45

The effect of the frequency of the currently fixated word N on the first fixation durations on word N for two Chinese groups in reading Chinese with different reading orders



Firstly, for the Upper Intermediate group, it can be observed that when participants read Chinese texts first (the red line), their first fixation durations were more influenced by the frequency of the currently fixated word, as indicated by the steepness of the slope. It means that as the word becomes more frequent, the first fixation durations on the word get shorter. Secondly, for the Advanced group, we also find a greater effect of word frequency if they Chinese texts is read first (the red line). In short, we observe a similar trend for both Chinese groups in both conditions. Overall, the Upper Intermediate group who read Chinese texts first showed the shortest first fixation durations among the four conditions. Based on the statistical result report in Appendix 8, it can be stated the effect of the frequency of the currently fixated word on the first fixation durations on it is statistically negatively significant for the Upper Intermediate group when they read Chinese first ($p = 0.01$).

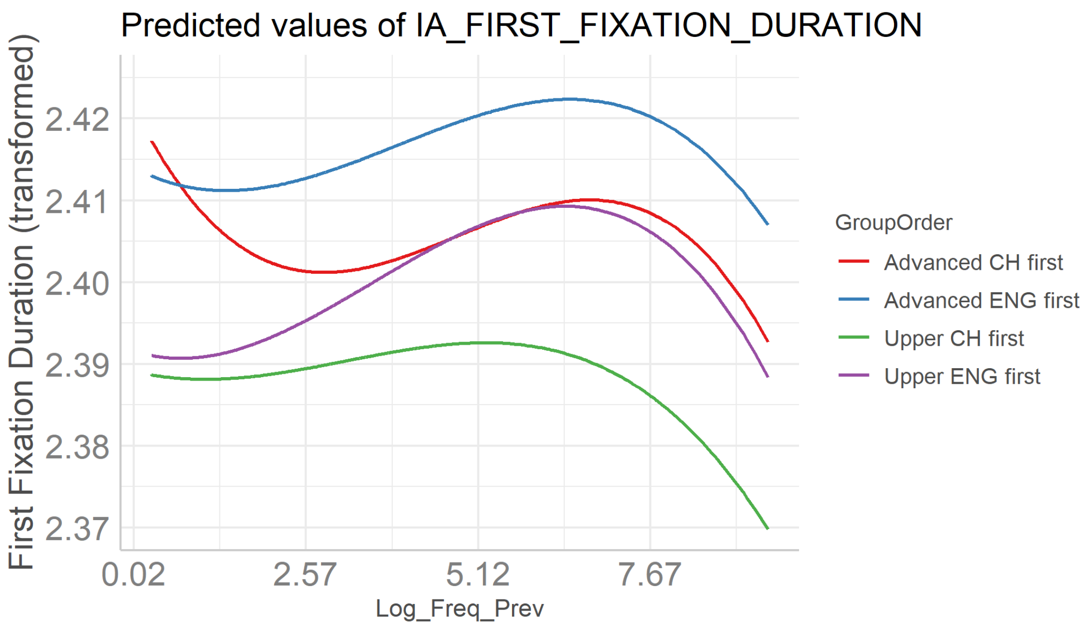
A notable observation is that for both groups, the effect of the frequency of the word they were fixating on had a greater impact on their first fixation durations when they began by reading in Chinese. A final noteworthy observation is that for both groups, a greater influence of the fixated word's frequency on the first fixation durations was seen when they began with reading Chinese.

8.2.3 The Effect of the Frequency of Word N-1

According to the modelling results, the frequency of the previous word N-1 also affects the first fixation durations in reading Chinese. The plot in Figure 46 shows how the first fixation durations of the two groups change as the frequency of the previous word changes.

Figure 46

The effect of the frequency of the previous word N-1 on the first fixation durations on word N for two Chinese groups in reading Chinese with different reading orders



Based on Figure 46 provided, we can see that the Upper Intermediate group that started reading in Chinese (green line) had the shortest first fixation durations compared to the other conditions. This implies that this group was quicker at recognising words in Chinese before they switched to reading in English.

In contrast, the same group, when they read English texts first (purple line), took longer to recognise words in Chinese. This suggests that reading in a second language (L2) first may have impacted their word recognition efficiency in their first language (L1).

For the Advanced group, the trend is more complex. When they read Chinese texts first (red line), their first fixation durations were shorter at very low frequencies of the previously fixated word, indicating faster recognition. This trend reverses as the frequency increases, peaking at a moderate frequency before decreasing again. This could mean that for less familiar words, the Advanced group was very efficient in recognition after reading in Chinese, but this advantage lessened as word familiarity increased.

On the other hand, when the Advanced group read English texts first (blue line), their first fixation durations were generally longer across all frequencies but showed a similar trend with a peak at moderate frequencies. This indicates that reading in L2 English may affect their L1 Chinese word recognition, but the pattern of recognition across different word frequencies remains similar.

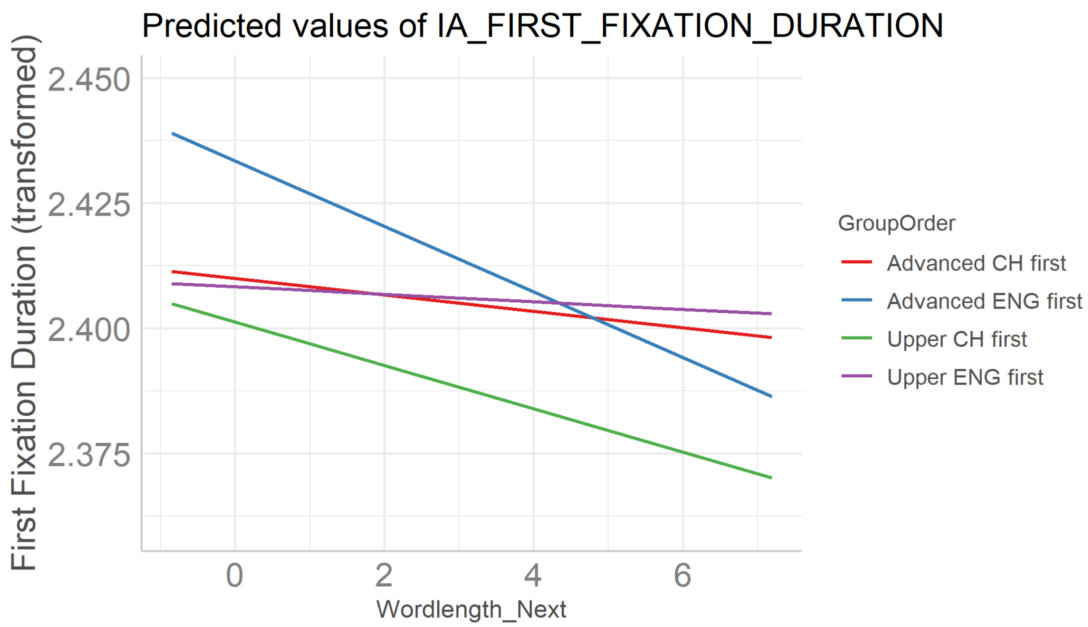
The Upper Intermediate group who read Chinese first (the green line) had the shortest first fixation durations among the four groups. The first fixation durations of the Upper Intermediate group reading English texts first were longer than in the other condition.

8.2.4 The Effect of the Length of Word N+1

The effect of the length of word N+1 was only significant as the linear effect.

Figure 47

The effect of the length of the next word N+1 on the first fixation durations on word N for two Chinese groups in reading Chinese with different reading orders



In the four conditions shown in Figure 47, Advanced group who read English first (the blue line) and Upper Intermediate group who read Chinese first (the green line) show a steeper slope of change in first fixation durations as the word length increases. For the Upper Intermediate group, the influence of the length of the next word N+1 on the first fixation durations of the currently fixated word N is greater if they read Chinese first ($p = 0.021$) than when they read English first ($p = 0.715$). The opposite pattern was found for the effect of the length of the next word N+1 on the first fixation durations of word N for the Advanced group (indicated by the red and blue line respectively). For the Advanced group, a greater effect is found in the condition when they read English texts first.

8.3 Summary

In predicting the variance of the first fixation durations of both Chinese groups in two reading orders, the frequency of the currently fixated word N, the length of the next word N+1 and the frequency of the previous word N-1 were found statistically significant. We will concisely reiterate the findings.

First, the effect of length of the currently fixated word N was not found to be statistically significant for the first fixation durations in reading Chinese for either group in either reading orders. Note that in the model for the first fixation durations in reading English, the effects of the length and frequency of the currently fixated word were found statistically significant for both the Upper Intermediate and the Advanced groups. Put differently, the effect of word length on the first fixation durations is absent from L1 reading but present in L2 in the same participants in a different language.

The second point worth mentioning is that Scaled_Word_Story_Order was only found significant for the Upper Intermediate group when they read Chinese first. This means that only when participants started with reading Chinese, their first fixation durations were affected by how far in the experiment they were.

The effect of the length of the next word N+1 was found significant for both Chinese groups while reading Chinese. In the model for first fixation durations in reading English as L2, we did not find a statistically significant effect of the length of the next word N+1 for the English native readers, but we did find it for the two Chinese groups. It is intriguing to note that the next word's length (N+1) only affected the Chinese groups in both their Chinese and English readings, but this factor did not influence the first fixation durations during English readings for the native group.

Finally, the effect of frequency of the previous word N-1 on first fixation durations while reading Chinese is significant for both groups of Chinese L1 readers. That effect did not reach significance in L2 reading of English texts. Taken jointly, the effect of the length of the next word and the frequency of the previous word might indicate the influence of Chinese orthography, rather than language proficiency and L2 exposure, given that the effect was found to be significant for Chinese readers only.

Chapter 9: The Chinese Reading Study - Gaze Duration

In this chapter, we focus on gaze duration in the Chinese reading study. Gaze duration (first pass reading time or first run dwell time) is defined as the sum of all the fixations made in a region until the eye leaves the region. It is assumed to relate to processing effort (more details can be found in Chapter 5). Recall that if the gaze duration on a word is long, this word is thought to cause more processing effort for readers.

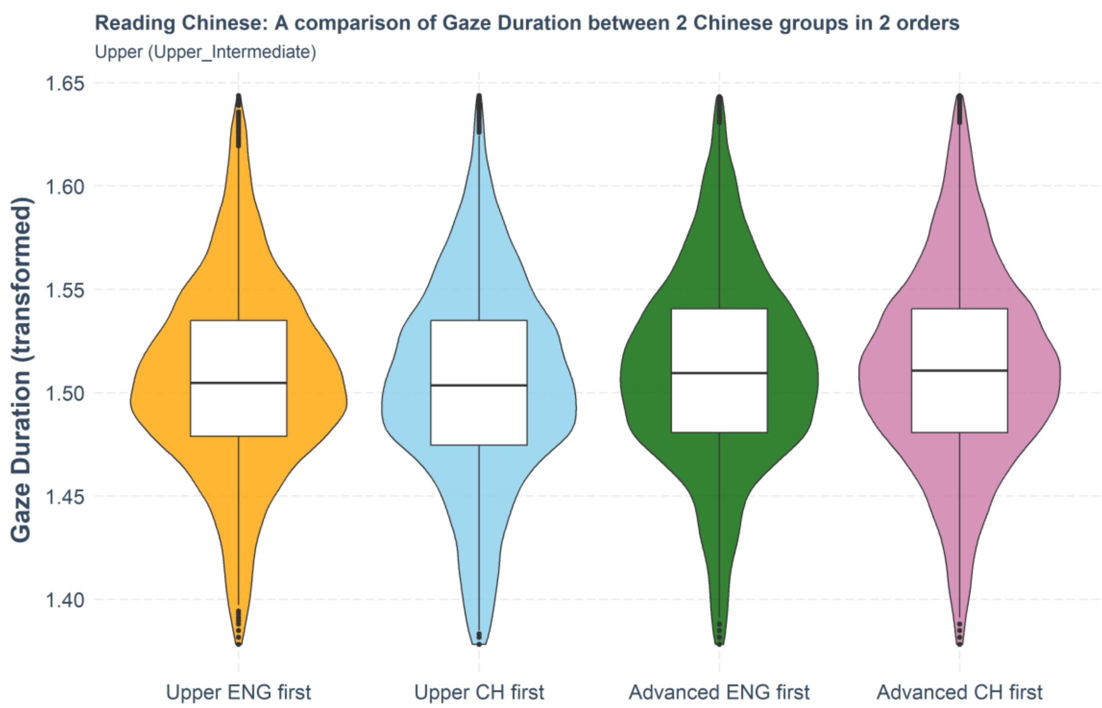
In this chapter, we will start with comparing gaze durations of the two groups of Chinese participants. We will also investigate possible influence of reading orders on the gaze durations of the two groups: Chinese texts first vs. English texts first. Finally, we tested the effects of benchmark variables such as frequency and length.

9.1 Preliminary Data Analysis

From Chapters 4 to 7, we studied how two Chinese groups with different English proficiency levels and reading orders processed English words. We discovered that advanced English readers benefitted earlier from reading in their native language (L1) when they switched to reading in English (L2). This is evidenced by both first fixation and gaze durations being significantly shorter for the Advanced group, while the Upper Intermediate group only showed significant improvement in terms of gaze durations. This suggests that for those more proficient in English with more exposure, being familiar with similar content in their native language helps with quicker word recognition and processing in English, starting from the very first word they look at. This advantage continues as they keep reading, as seen in their gaze durations. In the preceding paragraphs, we reviewed our findings on how reading in their native language (L1) first affected the gaze durations for both Chinese groups when reading English as a second language (L2). Moving forward, we will explore if and how reading in English (L2) first impacts the gaze durations when these groups read in their native language (L1). In Figure 48, we have depicted the distributional properties and salient statistical attributes of the gaze durations for both the Upper Intermediate and Advanced groups.

Figure 48

Violin plots of gaze durations of two Chinese groups in reading Chinese



The y-axis in Figure 48 represents the values of gaze durations after log transformation (see Chapter 3, Section 3.9.2 Data Preparation of the Chinese Reading Study for details of the transformation). Figure 48 shows that the mean of the Upper Intermediate group who read English texts first is slightly higher than that of the Upper Intermediate group who read Chinese texts first. As the values in Table 14 show, the mean value of gaze durations (after power transformation) of the Upper Intermediate who read English texts first was 1.507 (SD = 0.046), while the mean of the Upper Intermediate group who read Chinese text first was lower: 1.503 (SD = 0.049).

Table 14

Gaze durations of both Chinese groups in both reading orders in reading Chinese

Group	Mean	Median	SD	MAD
Upper ENG first	1.507	1.505	0.046	0.042
Upper CH first	1.503	1.504	0.049	0.045
Advanced ENG first	1.511	1.510	0.047	0.043
Advanced CH first	1.511	1.511	0.048	0.045

A z-test was conducted to test whether having previously read English texts with similar content had a significant effect on the gaze durations on the target word of the Upper Intermediate group when reading Chinese. It was found that, in the Upper Intermediate group, there is a statistically significant difference in gaze durations for participants who English texts first and those that read Chinese texts first ($z = 7.5349$, $p < 0.0001$). When reading English first this group is slower.

There was no statistically significant difference in the gaze durations between the two reading orders for the Advanced group. There was a small difference in dispersion, i.e., variation of the gaze durations for this group showing less/more variation when they saw English texts before Chinese originals.

The main findings from initial descriptive statistical analysis can be summarised in three points. Firstly, the Upper Intermediate group had significantly shorter mean gaze durations when they read Chinese texts first. The results are consistent with the first fixation durations in reading Chinese. Secondly, the Advanced group, did not benefit from reading English texts first. These results are also in line with the results for first fixation durations.

Transitioning to the next phase of our analysis, we will employ advanced statistical techniques to examine the influence of key predictors on gaze duration during the Chinese reading study.

9.2 Statistical Modelling the Gaze Duration Data

In this section, gaze durations (IA_FIRST_RUN_DWLL_TIME) were analysed using a linear mixed-effects model. This model was fitted using the lmer function from the lme4 package (Version 1.1-26) in the R Environment for Statistical Computing (Version 3.3.1).

We will examine how different predictors of word level and the text level affect the gaze duration in reading Chinese. These properties fall into two types. The first type includes properties at the word-level. We begin with the properties of the currently fixated word (word N) by taking its length and frequency into account. More than that, the properties of word N's neighbouring words, N-1, and N+1 were also added to the model to test their possible influences on the gaze durations of the currently fixated word. We also include a text-level property in the model (the word order used as a control variable). Predictors are transformed where supported by the Box Cox test

(Chapter 3, Section 3.9.2 Data Preparation of the Chinese Reading Study), to facilitate statistical modelling.

The most parsimonious model was retained, and the results are summarised in the following table.

Table 15

A complete list of variables included in the most parsimonious model to predict the gaze durations on word N in reading Chinese

Property Types	**Variable Names**	**Explanation**
Word-level Properties	Log_Freq_N	the frequency after logarithm of the current fixated word N
	Wordlength_Next	the length of the upcoming word, N+1
	Log_Freq_Prev	the frequency of the word to the left of the current fixated word, i.e., word N-1
	Log_Freq_Next	the frequency of the upcoming word, N+1
Text-level Property	Scaled_Word_Story_Order	the combined order of a word in a story and the order of a story in the reading study

The specification of the final best model is:

```
IA_GAZE_DURATION_PT ~
    GroupOrder/ (
      Scaled_Word_Story_Order +
      Log_Freq_N +
      Wordlength_Next +
      poly(Log_Freq_Prev, 3) +
      Log_Freq_Next) +
     (1 | Participant_ID) +
     (1 | Story_ID) +
     (1 | Word_ID)
```

A complete report about the results of this model can be found in Appendix 9.

As the formula indicates, we ran polynomial regressions to test for possible nonlinear relationships, which were also reported in previous studies (Kliegl et al., 2004; Ma et al., 2015). In our model, the linear Scaled_Word_Story_Order, linear Fre_log_N, and the nonlinear Fre_log_prev and Wordlength_Next were found to be statistically significant (indicated by the anova function in R). We also added the GroupOrder based on the statistically significant difference in the gaze durations between the two groups and two reading orders, Upper_Intermediate_ch, Upper_Intermediate_en, Advanced_ch, and Advanced_en. Then, we also added Participant_ID, Story_ID, and Word_ID as random effects.

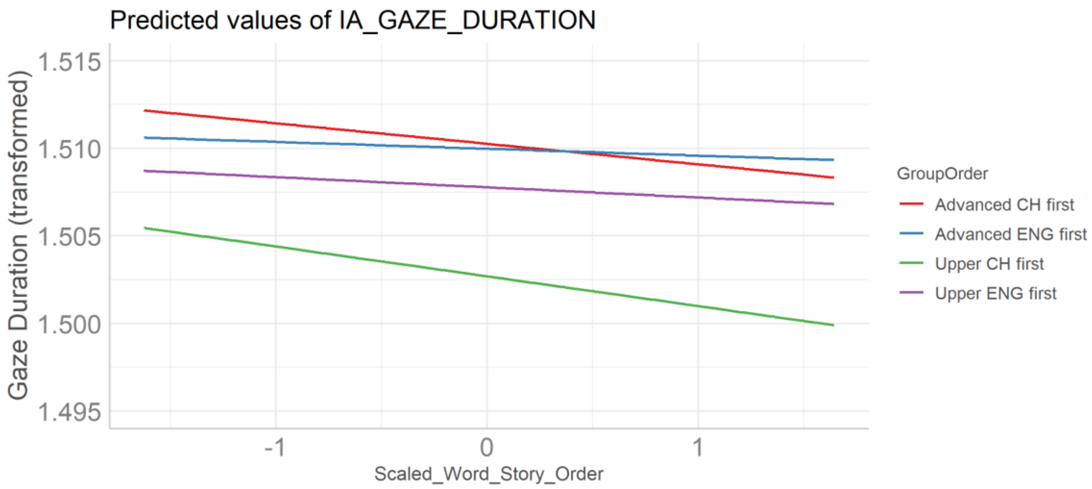
The model's total explained variance R2 is 0.12. It means that this model can explain 12% of variation in the gaze durations using the set of predictors as specified in the model.

9.2.1 The Order Effect

Note that we controlled the possible effects of word order as a fixed effect. The gaze durations in reading Chinese texts are shown in Figure 49 according to the model's predictions of the order of the currently fixated word. More specifically, we examined how these relationships are different for the two groups of Chinese participants in two reading orders.

Figure 49

The effect of the Scaled_Word_Story_Order on the gaze durations on word N for two Chinese groups in reading Chinese with different reading orders



The x-axis represents the word order. The range was from -1.62573 to 1.64335 (after scaling). The larger the value on the x-axis is, the closer position of the word is to the end of the text and the end of the reading task. The y-axis represents the gaze durations (with a range from 1.495 to 1.515, after transformation and scaling).

In Figure 49 we graphically represented the effect of the word order on the gaze durations of two Chinese groups in two reading orders in reading Chinese as L1. To begin, it is important to note that the gaze durations of the Upper Intermediate group, which is considered less proficient in their second language (L2), were consistently shorter in both reading conditions when compared to the Advanced group. This is evident by comparing the green and purple lines (the Upper Intermediate group) which lie below the blue and red lines (the Advanced group). However, it is crucial to emphasise that based on the results of statistical analysis, the disparity in gaze durations between the Upper Intermediate and Advanced groups did not reach a level of statistical significance (detailed in Appendix 9).

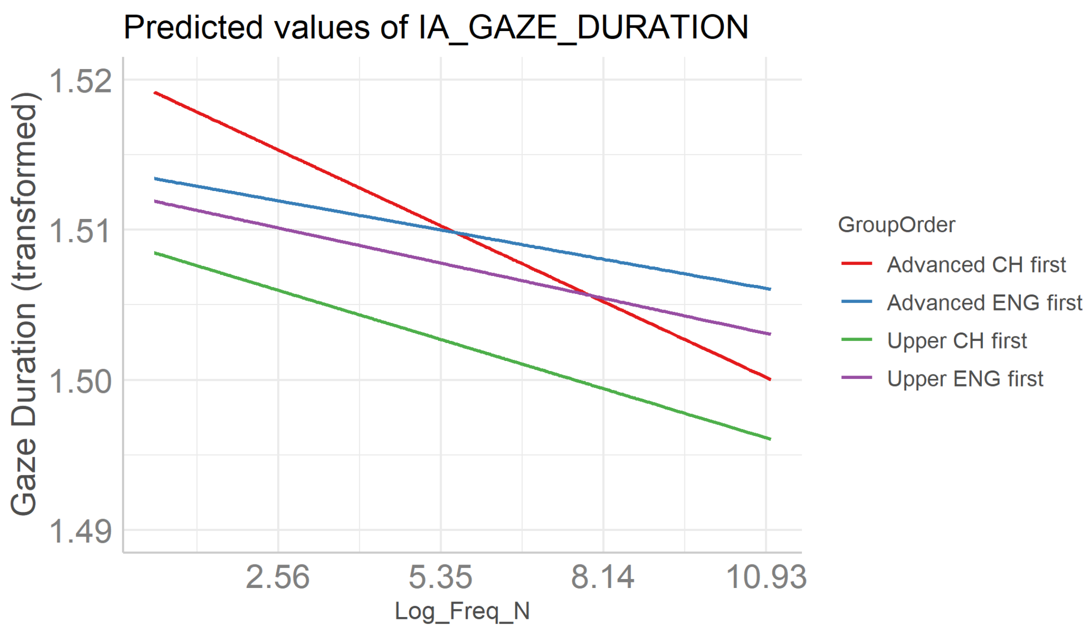
We can note two important pieces of information in Figure 49. First, the Upper Intermediate group (the green line and purple line) is more affected by the word order. As the experiment unfolds, Chinese L1 gaze durations become shorter, more so if they firstly read the stories in their native language. The patterns observed in both groups suggest that their gaze durations on words were more affected by the order of words and stories when they started by reading Chinese texts.

9.2.2 *The Effect of the Frequency of Word N*

Figure 50 summarises the interaction of word frequency by four groups, which distinguish between proficiency level and order of language.

Figure 50

The effect of the frequency of the currently fixated word N on the gaze durations on word N for two Chinese groups in reading Chinese with different reading orders



The x-axis represents the frequency, and the y-axis represents the gaze durations. In Figure 50, a downward trend is evident for both groups in either order, with four lines indicating a decrease in gaze duration as the frequency of the currently fixated word increases. More specifically, for both groups in both reading orders, as the frequency of word N increases, the gaze durations on the currently fixated word decrease. It is noticeable that the Advanced group who read Chinese first (shown by the red line) had a sharper decline in their trend compared to when they read English first (blue line). This suggests that for the Advanced group, word frequency had a bigger impact on how long they looked at words in Chinese if they read Chinese first.

Conversely, their gaze durations were more affected by the word frequency when they did not start with similar content in their second language. Note that the relations between the frequency of the currently fixated word N and the gaze durations on the currently fixated word N are statistically significant for both groups in both reading orders (Advanced_ch, $p < 0.001$, Advanced_en, $p < 0.012$, Upper_Intermediate_ch, $p < 0.001$, Upper_Intermediate_en, $p = 0.004$). Further details are given in Appendix 9.

Remember, we observed no significant impact of the length and frequency of the fixated word on first fixation times in Chinese reading for either group. However, for gaze durations in Chinese, the frequency of the fixated word did show a significant eff ect, unlike word length.

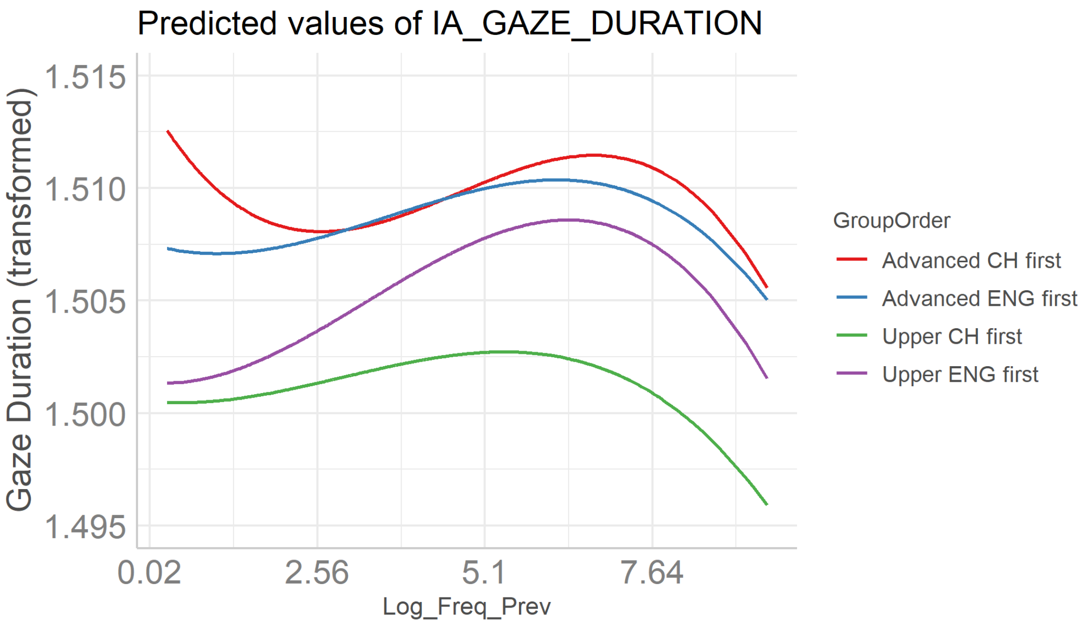
In contrast, Chapter 5 highlighted significant effects of both length and frequency of the fixated word on gaze durations in English reading. Specifically, longer English words resulted in longer gaze durations for both Chinese groups, Upper Intermediate and Advanced. This link between word length and gaze duration in English, not seen in Chinese reading, is noteworthy and merits further investigation.

9.2.3 The Effect of the Frequency of Word N-1

The frequency of the previous word N-1 was also found to be statistically significant to affect the gaze durations of Chinese participants. Figure 51 reveals the correlations between the frequency of the previous word N-1 and the gaze durations on word N for two Chinese groups when reading Chinese.

Figure 51

The effect of the frequency of the previous word N-1 on the gaze durations on word N for two Chinese groups in reading Chinese with different reading orders



The x-axis represents the frequency of the previous word and the y-axis represents the gaze durations.

As shown in Figure 51, for both the Upper Intermediate and Advanced group, there were significant nonlinear relations between the gaze durations on the current word N and the frequency of the previous word N-1. Both groups exhibited a similar pattern when they read Chinese texts after reading English: they spent more time on the current word if the previous word was more common (as shown by the blue and purple lines). This indicates that familiar preceding words cause readers to linger longer on the current word. However, this effect was stronger in the Advanced group than the Upper Intermediate group when they read Chinese first (indicated by the red and green lines). The influence of the previous word's frequency was only significant for the Upper

Intermediate group at a basic level when reading Chinese first, but for both groups, the relationship was significant at a more complex, quadratic level. This means the effect of the previous word's frequency on gaze duration is not straightforward but has a non-linear pattern, significant for the Advanced group in both conditions, especially when they began with Chinese reading. The gaze durations of the Upper Intermediate group were still generally shorter than that of the Advanced group as the green line and purple line are below the blue and red lines.

We need to consider two important points from our findings. Firstly, the patterns we see in how gaze durations relate to the frequency of the previous word in Chinese mirror our earlier observations of first fixation durations in Chinese, as discussed in Chapter 8. For both measures, the two groups showed complex, non-linear relationships, suggesting that their reading behaviour cannot be captured by simple linear predictions; it is influenced by more intricate interactions.

Secondly, this complexity contrasts with our findings from Chapter 5, where the gaze durations of the two Chinese groups in English reading were linearly related to variables. When reading Chinese, their native language, the readers showed significant non-linear relationships at multiple levels (linear, quadratic, and cubic), indicating a more layered reading process than in English.

In short, the reading patterns of Chinese participants are more complex when they read in Chinese than in English, pointing to a reading process that is influenced by a web of dynamic factors, rather than a one-way directional influence.

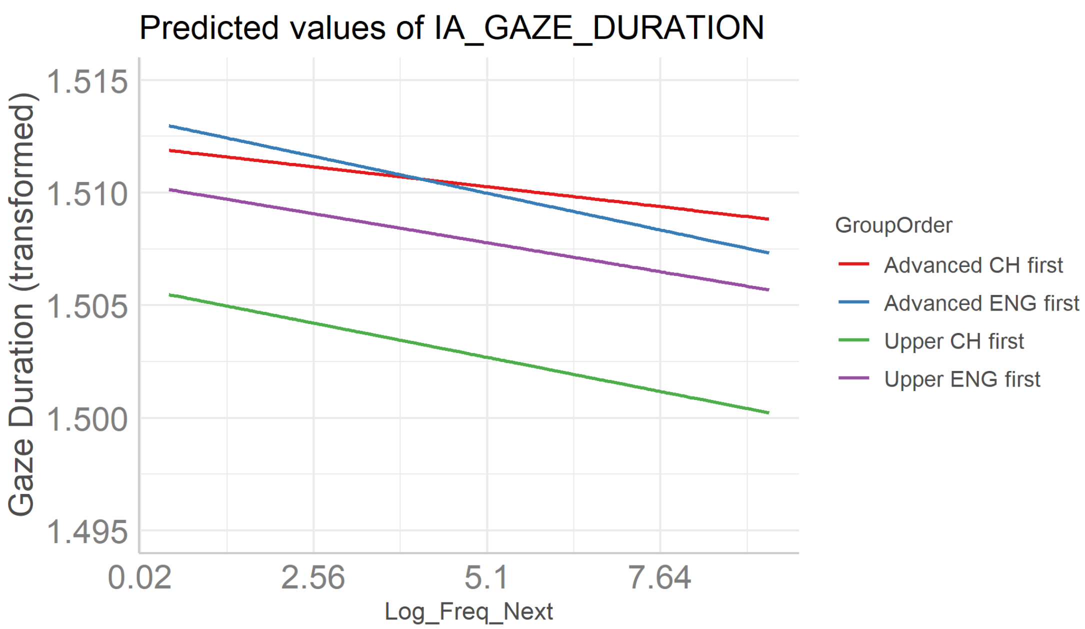
9.2.4 The Effect of the Frequency of Word N+1

The last variable we found to be statistically significant in our model to predict the gaze durations on the currently fixated word N is the frequency of the next word N+1.

In Figure 52, we graph the relationship between the frequency of the next word and gaze durations on the current word in Chinese reading to see if there is a difference between the two Chinese groups with different reading orders.

Figure 52

The effect of the frequency of the next word N+1 on the gaze durations on word N for two Chinese groups in reading Chinese with different reading orders



The x-axis represents the frequency of the next word N+1 and the y-axis represents the gaze durations.

As shown in Figure 52 to both groups with two reading conditions, there is a negative relation between the frequency of the next word N+1 and the gaze durations on the currently fixated word N, i.e., when the frequency of the next word N+1 increases, the gaze duration on the currently fixated word decreases. Among all the four conditions, again, the gaze durations of the Upper Intermediate group were shorter than that of the Advanced group.

Note that we did not find a statistically significant effect of the frequency of the next word N+1 in the model predicting the of the first fixation durations in reading Chinese for both groups. Besides, according to the model, the effects were only found to be significant when the Advanced group read English texts as L2 before they read Chinese ones, and when the Upper Intermediate group started directly with reading Chinese.

Our research yielded several important findings, which are outlined in three key points. Firstly, we observed a notable relationship with the frequency of the current word (N) in terms of gaze durations. This relationship emerged as significant, indicating that the more frequently a word occurs, the longer a reader may fixate on it during reading. Interestingly, this pattern did not extend to the first fixation durations, suggesting that the initial moment of word recognition is not influenced by frequency in the same way.

Secondly, the investigation into reading Chinese revealed that both the first fixation durations and gaze durations were significantly affected by the frequency of the word just read (N-1) and the length of the word coming next (N+1). These findings suggest that readers' engagement with a word is not isolated to that word alone but is also affected by their anticipation of the following word and the residual effect of the preceding word.

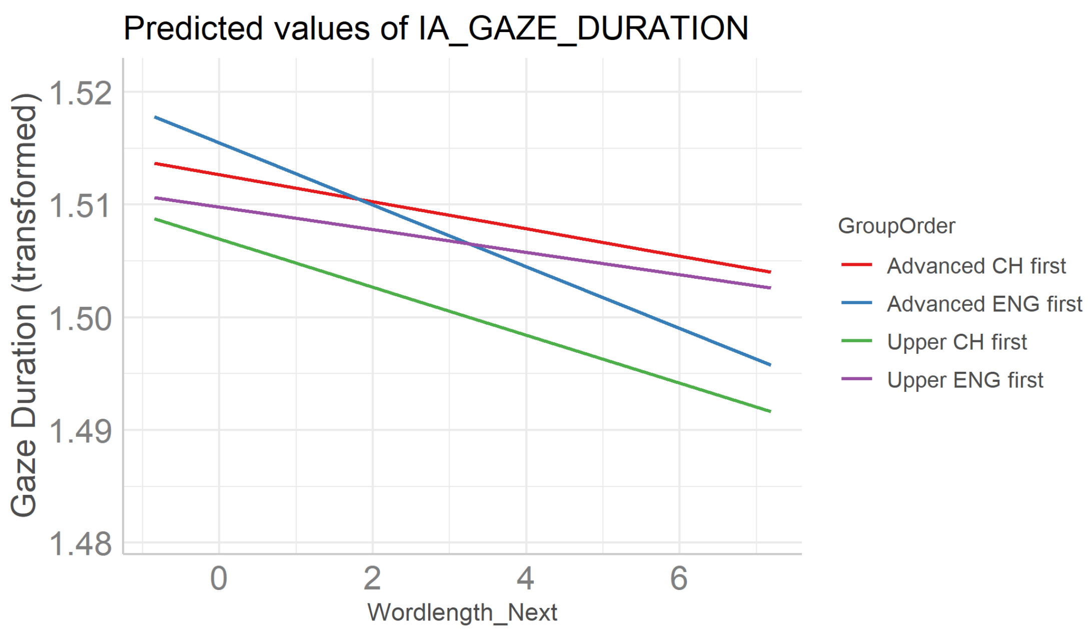
Lastly, the study did not uncover a statistically significant link between the length of the word just read (N-1) and the gaze durations in Chinese reading. However, when the participants read English as a second language, a different pattern emerged. In this context, gaze durations showed a significant correlation with both the length of the preceding word (N-1) and the frequency of the following word (N+1), pointing towards a nuanced interplay between word recognition and the sequential processing of text in a second language.

9.2.5 The Effect of the Length of Word N+1

The length of the next word was also found to be statistically significant to affect the gaze durations in reading Chinese. Figure 53 presents the effect of the length of the next word N+1 on the gaze durations on word N for two Chinese groups in reading Chinese. The x-axis in the figure is the length of the next word and the y-axis represents the gaze durations.

Figure 53

The effect of the length of the next word N+1 on the gaze durations on word N for two Chinese groups in reading Chinese with different reading orders



Our model demonstrates a significant impact of the length of the next word N+1 on the gaze duration of the current word N. Figure 53 illustrates that for both Upper Intermediate and Advanced groups, gaze durations decrease as the length of word N+1 increases, indicating that this factor is influential across different levels of Chinese reading proficiency and reading sequences. In particular, the Advanced group's gaze duration was significantly affected by the length of word N+1 when they read Chinese texts following English texts, while the Upper Intermediate group was similarly influenced when they started directly with Chinese texts.

The diminished gaze duration on word N, corresponding with the increase in length of word N+1, likely signifies anticipatory lexical processing. Readers are preparing for the longer word ahead, leading to quicker movement away from the current word. This suggests that readers employ strategic eye movement patterns to manage their focus and time more efficiently, an adaptive response to the cognitive demands of processing words of varying lengths. For additional information on these findings, Appendix 9 provides a complete detail regarding the modelling result.

In the last chapter, we noted an interesting finding regarding Chinese reading: for the Advanced group starting with English and the Upper Intermediate group starting with Chinese, the length of the following word (N+1) noticeably influenced how long they initially looked at a word. Essentially, there was a trend where readers spent less time looking at the current word when the next word was longer. This suggests a unique way that readers prepare for longer upcoming words.

An important finding to highlight is the comparison with our earlier observations of how the next word's length affected the reading of English as a second language by two groups of Chinese participants (as reported in Chapter 5). When reading English, the time these groups spent looking at a word was significantly shorter if the following word was longer. This "negative influence" means that the longer the next word, the quicker the readers moved on from the current one. The fact that these Chinese groups showed a stronger response to the length of word N+1 than native English speakers points to a distinct reading pattern. In essence, the Chinese readers reading in English were more affected by the length of upcoming words, reacting more to these changes than native readers would.

Chapter 10: The Chinese Reading Study - Total Reading Time

In this chapter, we will focus on the total reading time on the currently fixated word, for Chinese L1 readers reading Chinese texts. Recall that total reading time, as a late eye-movement measure, not only reflects lexical factors, but it is also indicating contextual, syntactic, or discourse-level components of the reading process. For example, syntactic ambiguity can lead to readers making longer fixations on a word, as well as more regressions to the prior context to integrate all information for the full comprehension. In this chapter, we will investigate the possible influence of two reading orders and standard set of predictors such as frequency and length of the target (N) and previous and following words (N-1, N+1) on the total reading times.

10.1 Preliminary Data Analysis

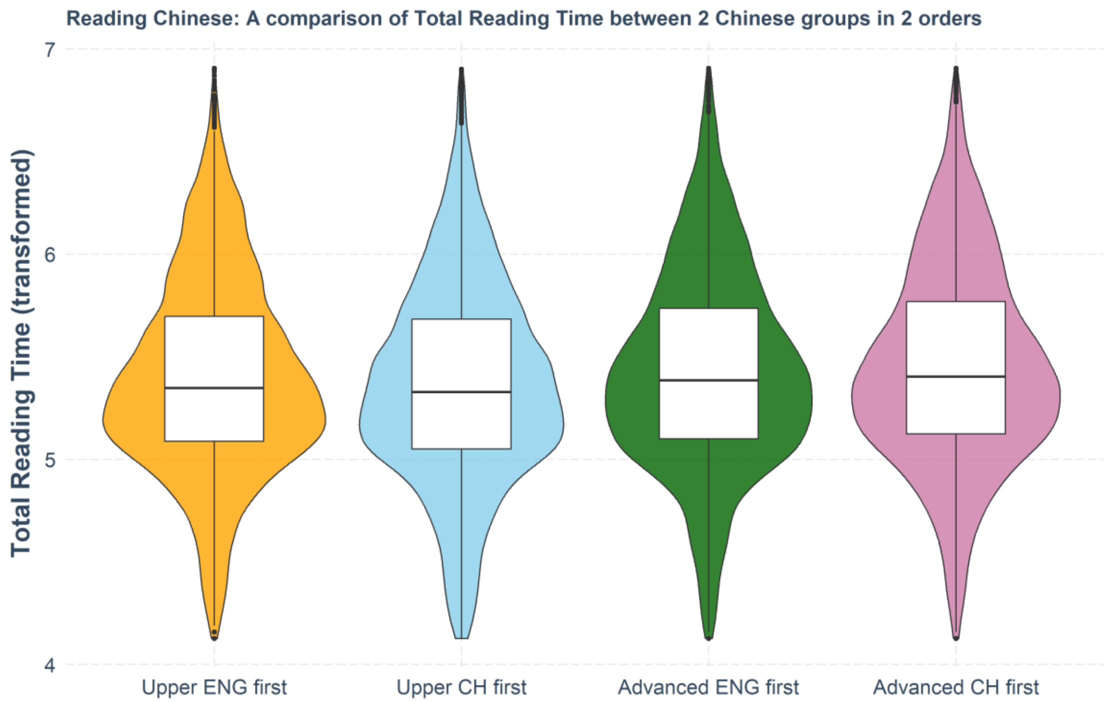
In the last two chapters, we compared how the different reading orders (reading Chinese texts first or second) affect the first fixation durations and the gaze durations of both groups in L1 reading. The main findings are: (1) For the Upper Intermediate group, the average duration of the initial fixation was notably shorter when they read Chinese first.; (2) Likewise, this group exhibited a significantly reduced average gaze durations when they read Chinese first.

What is more, recall that in the English reading study, both Chinese readers groups, i.e., more and less fluent, participants who read Chinese first had shorter total reading time than the participants who read English first; in addition, the effect was more pronounced for the Advanced group compared to the Upper Intermediate group. It indicates that the Advanced group profited more than the Upper Intermediate group from reading L1 texts first.

In Figure 54, we visualised the distributions of the total reading time of the two groups and two reading orders in reading Chinese.

Figure 54

Violin plots of total reading time of two Chinese groups in reading Chinese



The orange violin plot indicates the total reading time of the Upper Intermediate group when reading English first, while the blue one shows their total reading time when reading Chinese first. The green and pink violin plots represent the total reading time of the Advanced group for reading English first and Chinese first, respectively. The y-axis represents the values of Total Reading Time (log transformed, as discussed in Chapter 3, Section 3.9.2).

From Figure 54 we can observe that the mean total reading time for the Upper Intermediate who read English text first is higher than that of the Upper Intermediate group who read Chinese first as L1. Table 16 shows that the mean total reading time of the Upper Intermediate who read English texts first was 5.399 (SD = 0.486), while the mean of the Upper Intermediate group who read Chinese texts first was 5.363 (SD = 0.501). The z-test for difference showed that the difference is significant ($z = 4.2613$, $p < 0.05$). This means that reading English texts as L2 makes total reading time significantly longer for the Chinese texts as L1, for the Upper Intermediate group.

The mean total reading time of the Advanced group who read Chinese texts first was higher than the one who read English texts first. More specifically, the mean of the Advanced who read English texts first is 5.43 (SD = 0.489), and the mean of the Advanced group who read Chinese texts first is 5.449 (SD = 0.477). It means that for the participants in the Advanced group who read English first, their total reading time on words was lower than that of the ones who did not in reading Chinese. Put differently, reading texts in English as L2 helped Advanced group make shorter total reading time when reading Chinese texts as L1 if they read English texts first. The z-test for difference showed that the difference is significnat ($z = -2.1919$, $p = 0.02838$). However, the effect of is found weaker to the Advanced group.

Table 16

Total reading time of both Chinese groups in both reading orders in reading Chinese

Group	Mean	Median	SD	MAD
Upper ENG first	5.399	5.347	0.486	0.441
Upper CH first	5.363	5.328	0.501	0.466
Advanced ENG first	5.430	5.384	0.489	0.459
Advanced CH first	5.449	5.403	0.492	0.467

The main finding in this section is that the Upper Intermediate group did not have a much shorter total reading time when they started with English. Instead, after reading similar English texts, they took longer to read Chinese on average. This was similar to what we saw with their first fixation durations and gaze durations in Chinese reading. Those who began with English had longer average times for these measurements compared to those in the same group who read Chinese first.

10.2 Statistical Modelling the Total Reading Time Data

For modelling the total reading time (IA_TOTAL_READING_TIME_LOG) we made use of linear mixed-effects model (Baayen et al., 2008) and the lmer function from the lme4 package (Version 1.1-26) in the R Environment for Statistical Computing (Version 3.3.1).

We examined how predictors of word level and the text level affect the total reading time in reading Chinese. The word level predictors include the length and frequency of the currently fixated word (word N) and its neighbouring words (N-1 and N+1). The word order at the text level is set as a control variable.

After running the model and comparing models with R^2 values, the model that had the best fit was found and will be presented and plotted as follow. We listed the variables we tested in the model in Table 17. The second column provides the names of variables used in the models. The Note column gives a description about the definition of the variable in the model. The rightmost column presents whether the variable is found statistically significant in the final model.

Table 17

A complete list of variables included in the most parsimonious model to predict the total reading time on word N in reading Chinese

Property Types	Variable Names	Explanation
	Wordlength_N	the length of the current fixated word N
	Log_Freq_N	the frequency after logarithm of the current fixated word N
Word-level Properties	Wordlength_Next	the length of the upcoming word, N+1
	Log_Freq_Prev	the frequency of the word to the left of the current fixated word, i.e., word N-1
	Log_Freq_Next	the frequency of the upcoming word, N+1
Text-level Property	Scaled_Word_Story_Order	the combined order of a word in a story and the order of a story in the reading study

The model specification was as follows.

```
IA_TOTAL_READING_TIME_LOG ~
    GroupOrder/ (
    Scaled_Word_Story_Order +
    Wordlength_N +
    Log_Freq_N +
    Wordlength_Next +
    poly(Log_Freq_Prev, 3) +
    Log_Freq_Next) +
    (1 | Participant_ID) +
    (1 | Story_ID) +
    (1 | Word_ID)
```

A complete result can be found in Appendix 10. Here we focus on the main findings.

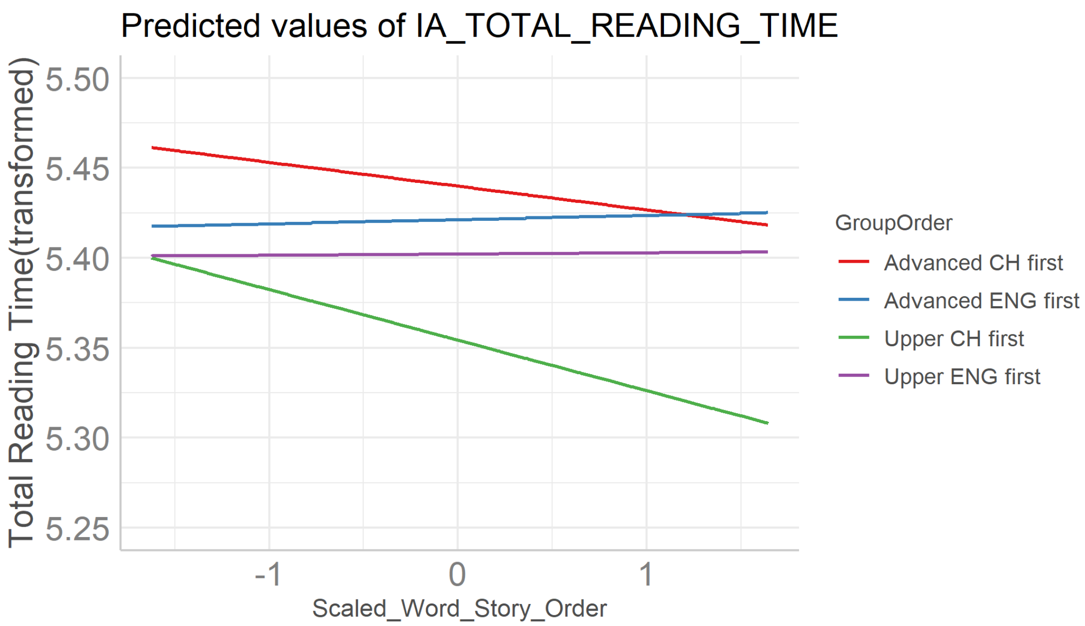
As the formula indicates, we ran linear mixed model allowing for non-linear relationships where needed (i.e., tested as significant) using polynomials. Scaled_Word_Story_Order, Wordlength_N, Fre_log_N, Wordlength_Next, Log_Freq_Next, and (nonlinear) Fre_log_prev were all statistically significant (see Appendix 10). All these effects were nested in the GroupOrder with four levels: two groups by two orders (Upper_Intermediate_ch, Upper_Intermediate_en, Advanced_ch, and Advanced_en). Finally, the random effects of Participant, Story, and Word contributed to the model fit. The model's total explained 15% of variance in the total reading time.

10.2.1 The Order Effect

As previously stated, we treated the effect of order as a control variable. We plotted the relations between the order and the total reading time for each combination of group and order in Figure 55.

Figure 55

The effect of the Scaled_Word_Story_Order on the total reading time on word N for two Chinese groups in reading Chinese with different reading orders



The x-axis in the figure represents the order in the Chinese reading study. The larger the value on the x-axis the position of the word is closer to the end of the overall reading task. The y-axis represents the total reading time.

When both groups started with Chinese texts, there was a clearer negative connection between the order of words in a story and the total time spent reading, as shown by the red line for the Advanced group and the green line for the Upper Intermediate group. Essentially, both groups showed significant results: the Upper

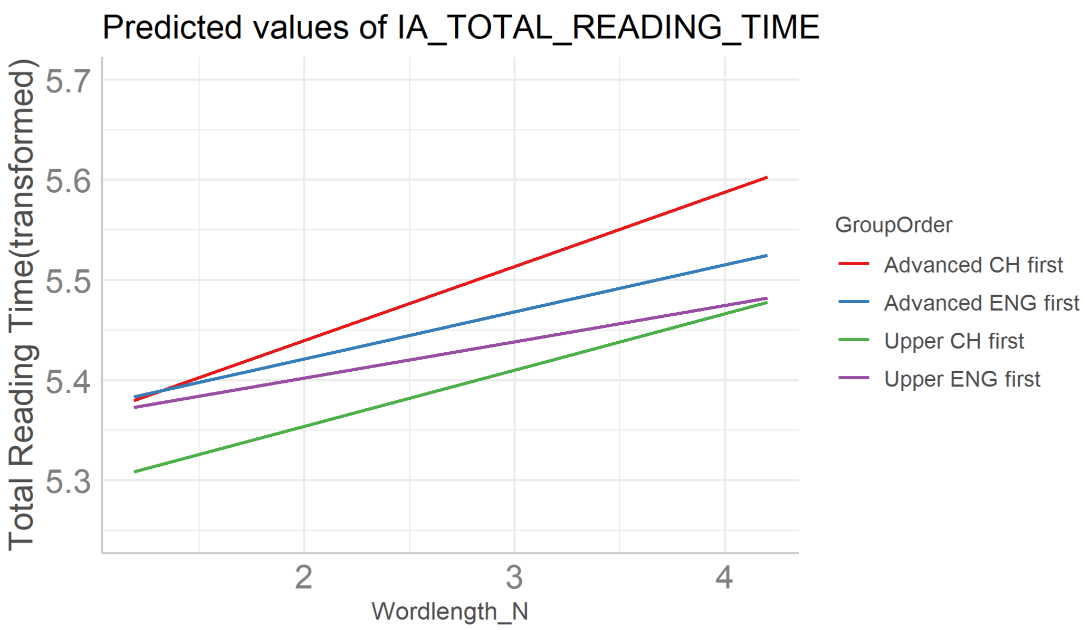
Intermediate group with a p-value of less than 0.001, and the Advanced group with a p-value of 0.043. In summary, when the Upper Intermediate group started with Chinese texts, their first fixation and gaze durations were significantly affected by the order of words and the story. Similarly, for both groups, the order of words and story had a significant impact on the total reading time when reading Chinese.

10.2.2 The Effect of the Length of Word N

Figure 56 shows the relationships between the length of the currently fixated word N and the total reading time.

Figure 56

The effect of the length of the currently fixated word N on the total reading time on word N for two Chinese groups in reading Chinese with different reading orders



The x-axis in the figure is the length of the currently fixated word. The y-axis represents the total reading time (after transformation from milliseconds).

As shown in Figure 56, all four lines have an increasing trend: as the word length of the currently fixated word N gets longer, the total reading time made on it also gets longer. In our study, as illustrated in Figure 56, we observed a consistent increase in total reading time with the lengthening of word length in the fixated words, a phenomenon that aligns with established research in the field. This correlation echoes the findings of a study reported by Gerth and Festman (2021), which highlighted significant effects of word length on total reading time. Similarly, Barton et al. (2014) reported a review to underscored the impact of word length in visual processing, noting its interaction with high-order effects like word frequency. These studies collectively reinforce our findings, suggesting that word length is a critical factor influencing reading time, thereby contributing to our understanding of reading dynamics and eye movement patterns in reading. For the Advanced group, when they started with Chinese texts, the relationship was statistically significant ($p = 0.001$). When they began with English texts, this relationship was still significant ($p = 0.023$), but it was less strong.

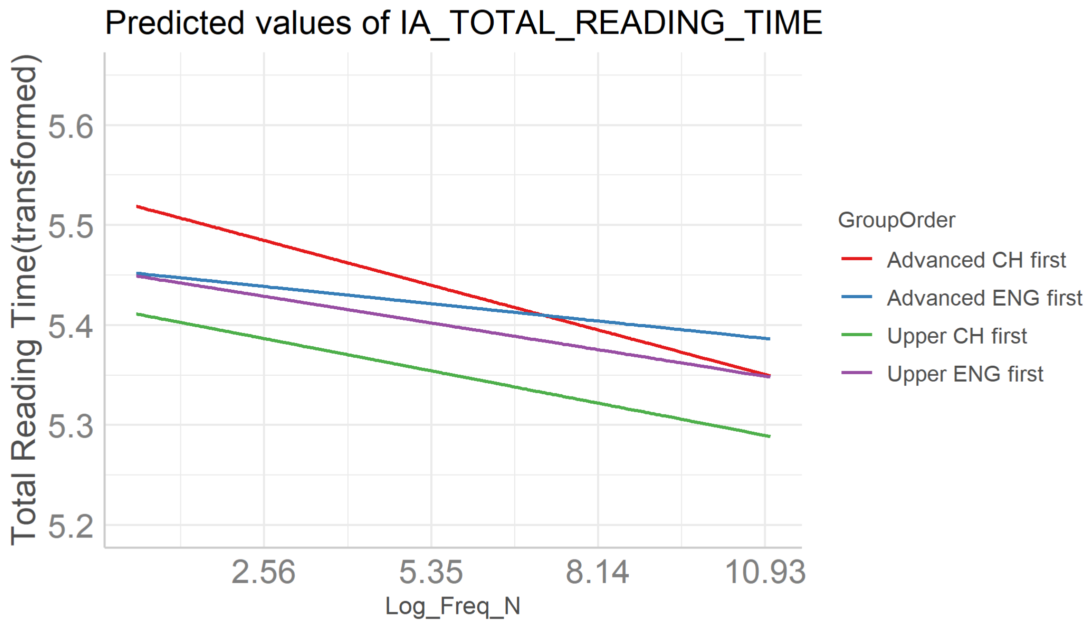
For the Advanced group, the impact of the length of the word they are currently focusing on is more pronounced when they read Chinese first compared to when they read English first. In the Upper Intermediate group, the relationship between the length of the current word and total reading time is only significant ($p = 0.028$) when they start with Chinese texts. This effect of word length was not significant when the Upper Intermediate group read English texts first.

10.2.3 The Effect of the Frequency of Word N

The effect of the frequency of the currently fixated word N on its total reading time is statistically significant as presented in Figure 57 for both groups in both reading orders.

Figure 57

The effect of the frequency of the currently fixated word N on the total reading time on word N for two Chinese groups in reading Chinese with different reading orders



The x-axis in the figure is the frequency (after the log transformation). The y-axis represents the total reading time (after power transformation from milliseconds).

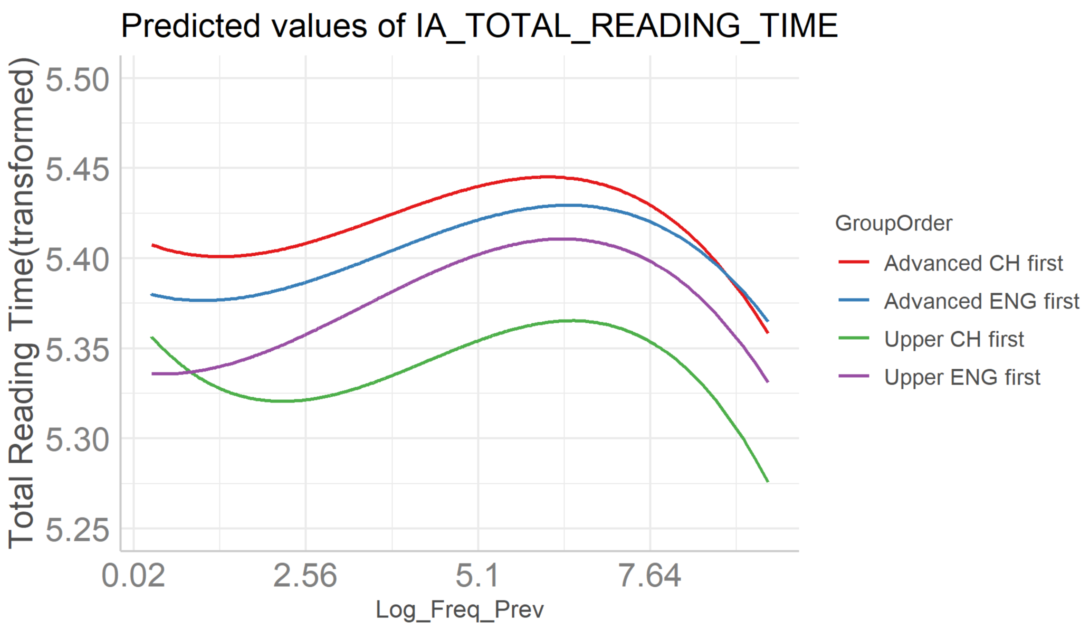
There are clear negative relations between the frequency of word N and the total reading time on it. More specifically, as the currently fixated word has a higher frequency, the total reading time on it gets shorter. For the Advanced group, the influence of how often the current word (word N) appears is a significant factor in total reading time only when they start with Chinese texts ($p = 0.001$). However, this effect is not significant when they read English texts first ($p = 0.107$). In contrast, for the Upper Intermediate group, the frequency of word N significantly affects total reading time ($p = 0.002$) in both reading orders. The impact is smaller (-0.027) but still significant ($p = 0.016$) when they read Chinese first, compared to when they read English first.

10.2.4 The Effect of the Frequency of Word N-1

The effect of the frequency of the previous word was also found to be significant. Figure 58 represents the relationship.

Figure 58

The effect of the frequency of the previous word N-1 on the total reading time on word N for two Chinese groups in reading Chinese with different reading orders



The x-axis in the figure is the frequency of the previous word. The y-axis represents the total reading time.

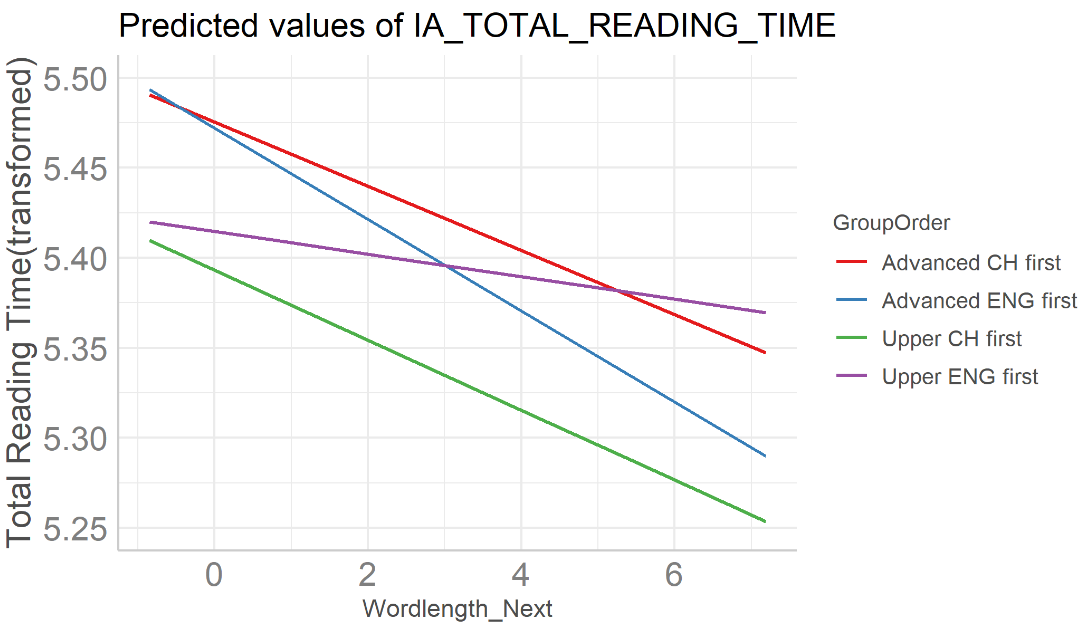
As shown in the plot in Figure 58, there were non-linear relations between the total reading time on the current word N and the frequency of the previous word N-1, for both groups and two language reading orders. The frequency of N-1 changes the direction of effect on total reading time, from 5.1 to 7.64.

10.2.5 The Effect of the Length of Word N+1

Besides the length of the currently fixated word N, the length of the next word was also found statistically significant to predict the variance of the total reading time on the currently fixated word to both Chinese groups in reading Chinese as L1. We present the relations in Figure 59.

Figure 59

The effect of the length of the next word N+1 on the total reading time on word N for two Chinese groups in reading Chinese with different reading orders



The x-axis in the figure is the length of the next word. The y-axis represents the total reading time (after log transformation from milliseconds).

As shown in Figure 59, as the length of the word N+1 increases, the total reading time for two groups by language conditions decreases. we found statistically significant relations between the length of the next word N+1 and the total reading time on the currently fixated word N in the Advanced group in both reading orders. There is a stronger effect of the length of the next word N+1 when the Advanced group started with Chinese texts (p = 0.026 when they read Chinese texts first and p < 0.001 as they read English texts first).

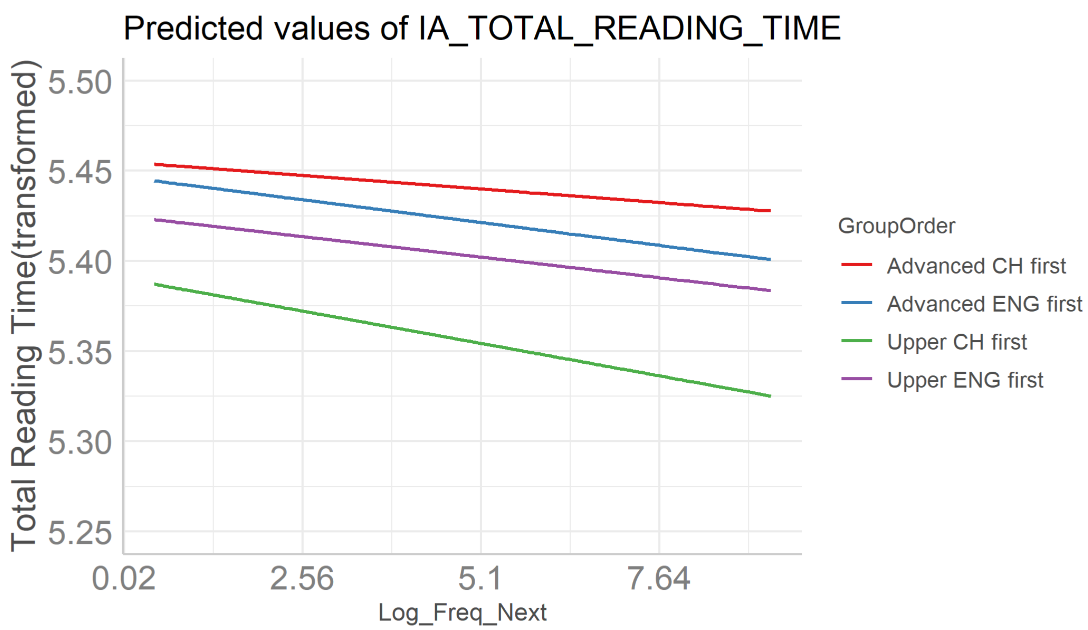
For the Upper Intermediate group, the effect of the length of the next word N+1 was only significant when participants in the group started with Chinese texts (p = 0.006).

10.2.6 The Effect of the Frequency of Word N+1

Frequency of the next word N+1 was also found to be a statistically significant predictor of the total reading time on the currently fixated word N. Figure 60 plots this relationship.

Figure 60

The effect of the frequency of the next word N+1 on the total reading time on word N for two Chinese groups in reading Chinese with different reading orders



The x-axis in the figure is the length of the next word. The y-axis represents the total reading time.

According to the modelling result, the effect of the frequency of word N+1 on the total reading time of the currently fixated word N is statistically significant in reading Chinese only for the Upper Intermediate group, and only if they read Chinese texts first ($p = 0.011$).

Chapter 11: Main Findings in Reading Chinese

In the previous three chapters, we fitted models to the first fixation durations, gaze durations and total reading time for Chinese participants reading Chinese texts (i.e., L1 reading). Moving forward in this chapter, we will continue the discussion. In other words, while in previous chapters we reported the results individually for each eye-movement measure, here, we will synthesise the findings of the text-level predictor and various word-level predictors, e.g., word length and frequency of the currently fixated word N, the previous word N-1 and the next word N+1. Table 18 lists the predictors (independent variables) that were found to be statistically significant to predict our chosen set of response variables (dependent variables).

Table 18

A list of variables as predictors that are statistically significant in the models capturing the three eye-movement measures as dependent variables in reading Chinese

	First Fixation Durations	Gaze Duration	Total Reading Time
Scaled_Word_Story_Order	√	√	√
Wordlength_N			√
Log_Freq_N	√	√	√
Wordlength_Prev			
Wordlength_Next	√	√	√
Log_Freq_Prev	√	√	√
Log_Freq_Next		√	√

Note. that the check mark (√) indicates statistical significance in the models we reported in the previous three chapters.

The following sections are organised in such a way to emphasise three aspects of here presented findings. Firstly, Section 11.1 focuses on the order effect. Section 11.2

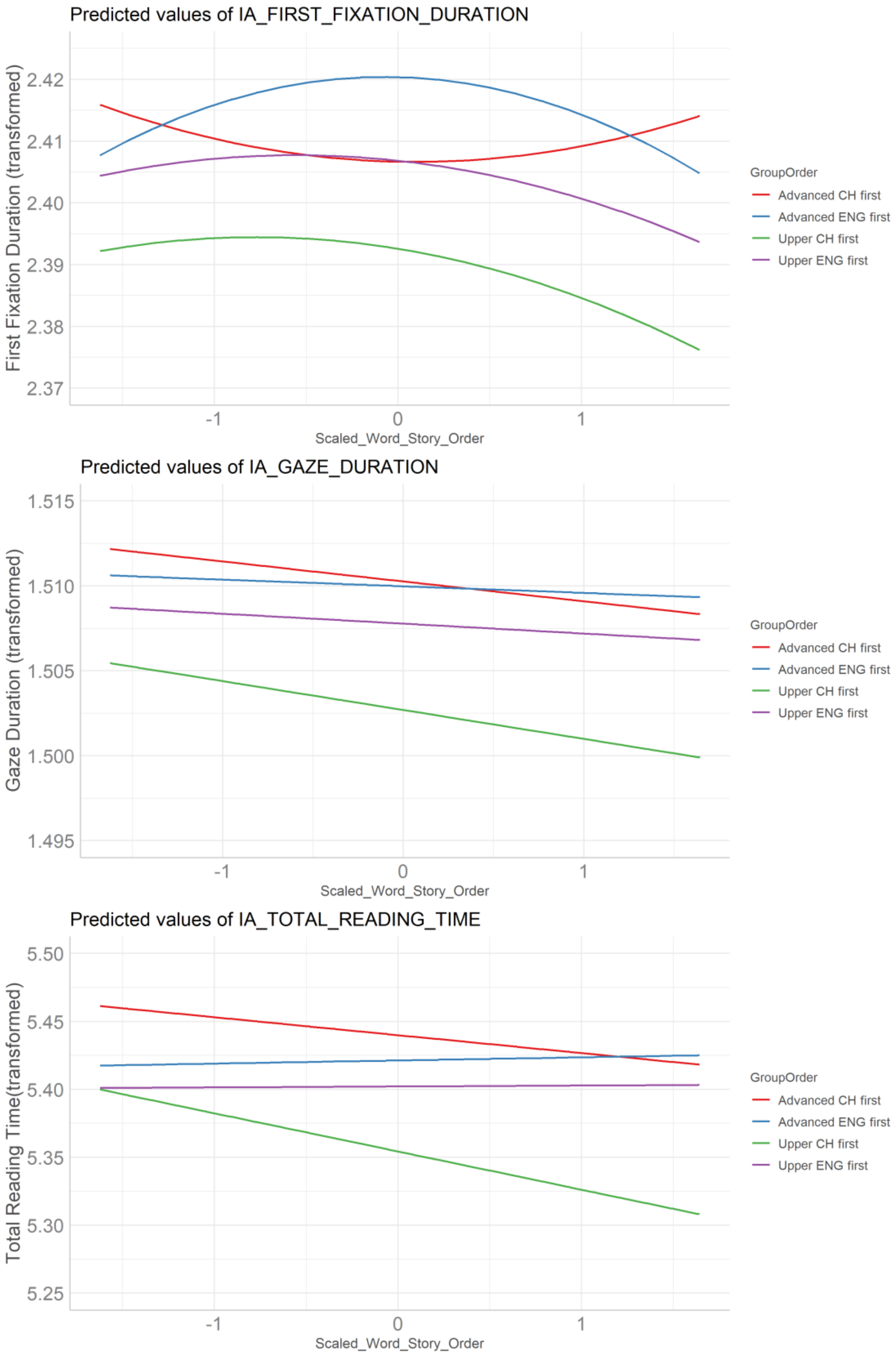
reports the effect of the properties of the target (currently fixated) word on fixation durations on this word. Section 11.3 and Section 11.4 summarise parafoveal processing, i.e., effects of the word to the left and to the right of the currently fixated word. In this section, we systematically compare the key features of parafoveal processing. Finally, in Section 11.5, we will present a summary.

11.1 The Order Effect

In the models we reported in the previous three chapters predicting the variance of First Fixation Durations, Gaze durations and Total Reading Time in reading Chinese, the Scaled_Word_Story_Order was found statistically significant. This means that the position of the currently fixated word in a text and of that text in the whole reading experiment significantly affected the three fixation-related variables.

Figure 61

Plots of the effect of the Scaled_Word_Story_Order on first fixation durations, gaze duration, and total reading time on word N in reading Chinese



Primarily, a visual examination of the data reveals an interesting pattern when reading in Chinese. Specifically, the relationship between Scaled_Word_Story_Order and the first fixation durations appears to be nonlinear, while it seems linear when considering gaze durations and total reading time.

This observation implies that the influence of Scaled_Word_Story_Order on reading behaviours differs depending on the specific aspect of reading being analysed. When it comes to the first fixation durations, readers' responses to changes in Scaled_Word_Story_Order do not follow a straightforward, linear pattern. Initially, their first fixation durations remain relatively constant up until the midpoint of the task. However, post this midpoint, there is a noticeable decline in the duration of their first fixations, which continues steadily until the completion of the reading task. As for the Advanced group, the blue line, representing the Advanced group who read English first, shows an initial increase in the first fixation duration as they progress through the reading task. This duration peaks around the midpoint and then gradually decreases towards the end of the experiment. On the other hand, the red line, depicting the Advanced group who read Chinese first, begins higher than the blue line, suggesting longer first fixation durations at the start. This duration decreases slightly as the task progresses, then levels off in the middle before gently rising again as the readers approach the end of the reading experiment. It suggests that the impact on fixation duration varies across different levels of Scaled_Word_Story_Order.

In contrast, for gaze durations and total reading time, the relationship appears more linear, indicating a more predictable and consistent effect of

Scaled_Word_Story_Order on these reading metrics. This means that progress over Items/Trials leads to consistent decrease in gaze durations and total reading time.

In terms of between group comparison, for the Upper Intermediate group, there was a declining trend to both reading order meaning that as the word is more towards the end of the study, the first fixation duration on the currently fixated word to the Upper Intermediate group becomes shorter (see the blue and purple lines). However, for the Advanced group, we found quite opposite patterns. In the Advanced group that started with Chinese texts (red line), their first fixation durations on words shortened as they read, up to the mid-point of the study. After reading half of the texts, these durations increased towards the end of the study. On the other hand, when this group read English texts first (blue line), they initially had longer first fixation durations in the Chinese study. However, these durations decreased towards the end, indicating faster word recognition.

The lines for reading Chinese first (red and green) have steeper slopes than those for reading English first, showing a more pronounced effect of word/story position on gaze durations and total reading time. This suggests that for both groups, when they read Chinese texts (their first language) directly, their overall word processing speed (including recognition, syntax, and context) increased as they progressed through the study.

11.2 The Effects of the Word N

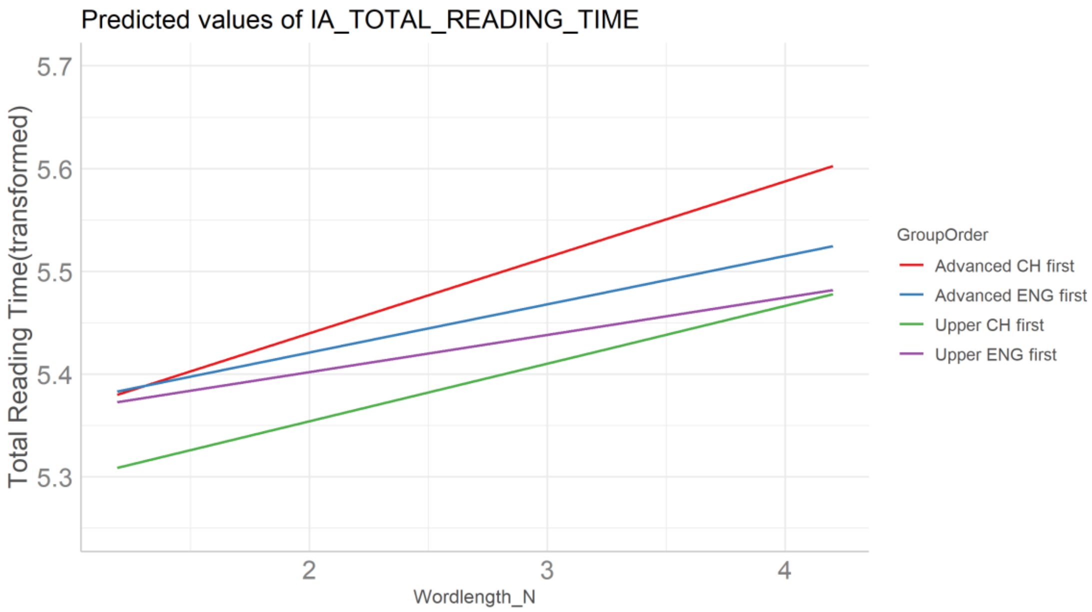
In this section, we provide a summary of how the length and frequency of the word currently fixated upon affect the target word. The discussion will initially focus on the impact of the word's length, and then proceed to analyse the effect of its frequency.

11.2.1 Length of the Word N

In this subsection, we report the word length effect of word N on the reading duration measures. What we found is that the length of the currently fixated word N only influenced the late measure, total reading time rather than the first fixation durations and gaze durations.

Figure 62

Plots of the effect of the length of the currently fixated word N on first fixation durations, gaze duration, and total reading time on word N in reading Chinese



The general trend of the four conditions is the same, and they all show a positive correlation which means that as the length of the currently fixated word increases (from 1 character to 4 characters), the total reading time on this word gets longer. The main findings across the two groups highlight two patterns. First, the Advanced group (red line for Chinese first, blue for English first) shows a stronger link between the fixated word's length and total reading time when reading Chinese first. Second, the Upper Intermediate group (green line for Chinese first, purple for English first) displays a similar trend. These patterns suggest that for Chinese participants, reading Chinese texts (L1) first leads to a more pronounced effect of word length on reading time than when they start with English (L2) texts. Across the groups, the Upper Intermediate group reading Chinese first had the shortest total reading time, followed by those reading English first. The Advanced group had longer total reading time in both conditions, with the highest for those starting with Chinese texts. The difference in total reading time between the two groups reveals an interesting insight into the reading abilities of the Upper Intermediate group, who is less proficient in reading English with less exposure to the second language (L2). This group demonstrated faster reading times in their first language (L1), as indicated by their total reading time.

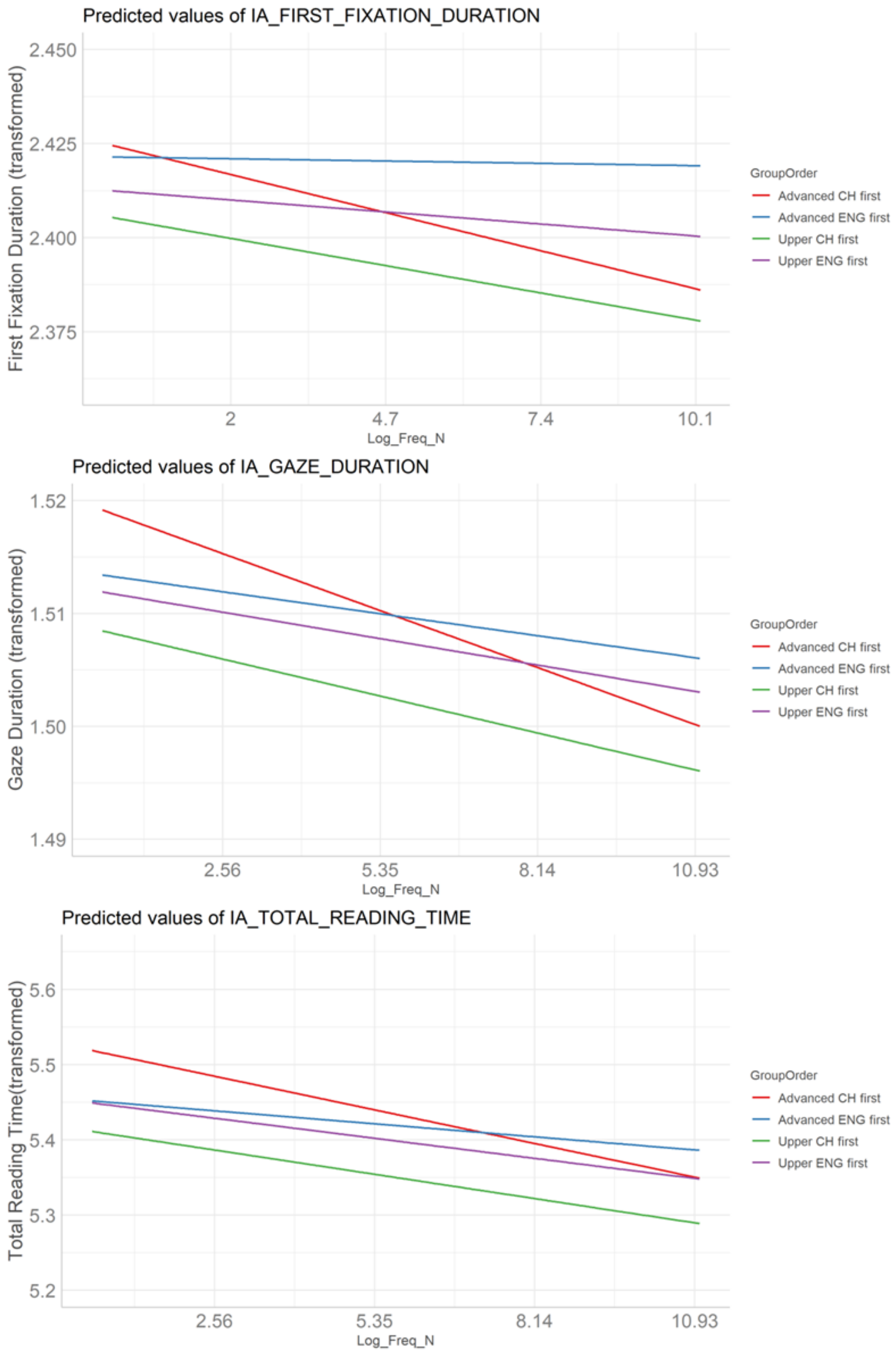
This observation indicates that the Upper Intermediate group's proficiency in their native language (L1) likely led to faster and more efficient reading in L1. Essentially, their solid grasp of their primary language seems to have enabled quicker understanding and processing in L1. However, this raises a question: does being a better reader in L1 lead to less efficiency in L2? In other words, their strong performance in L1 might be interfering with their ability to read as effectively in their second language (L2).

11.2.2 Frequency of the Word N

Frequency of the target word N is a significant predictor of all three reading duration measures, also for both groups of Chinese readers and under the different reading orders.

Figure 63

Plots of the effect of the frequency of the currently fixated word N on first fixation durations, gaze duration, and total reading time on word N for all three groups



As the frequency of the currently fixated word gets higher, the first fixation durations, gaze durations and total reading time on this target word gets shorter. For all three measures, we also found word frequency effect for both groups of Chinese readers when they read in their L1 (Chinese) first as L1 (see Figure 63 and notice the steeper slopes of the red line and green line). This implies that starting reading in L1 leads to a stronger word-frequency facilitation.

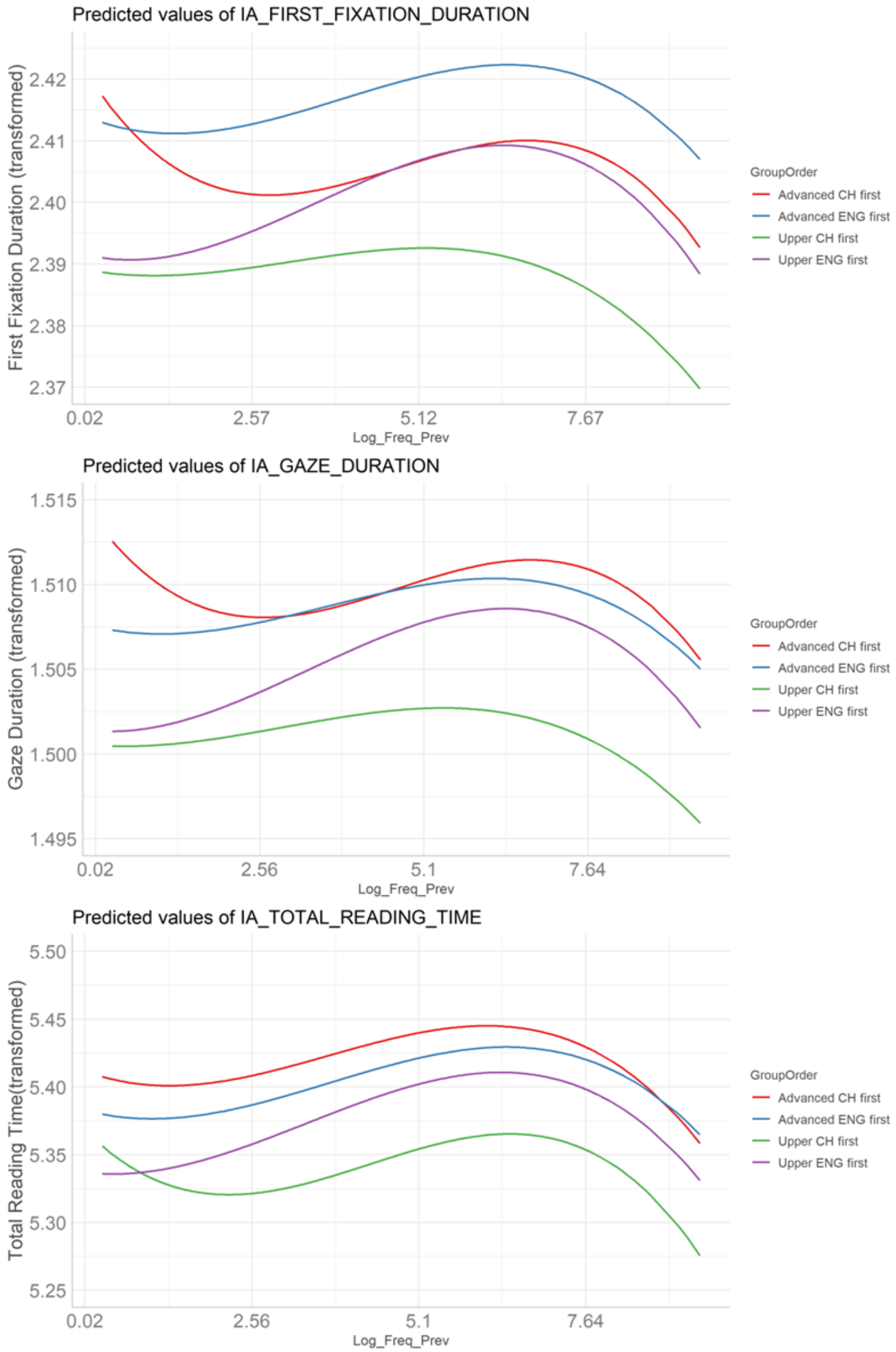
This observation underscores the influence of language proficiency and linguistic differences on reading strategies. It suggests that these participants may have adapted their reading approaches differently when transitioning from their L1 to L2, leading to variations in the degree of sensitivity to word frequency. This observation highlights the significant role that language proficiency and the inherent differences between languages play in shaping reading strategies. It implies that participants, particularly those in the Advanced group, might employ distinct reading techniques when they switch from their first language (L1) to their second language (L2). This switch can lead to changes in how sensitive they are to the frequency of words, potentially due to the varying cognitive demands of reading in a non-native language. As they advance through the reading task, these readers might adjust their focus and processing speed, which is reflected in the alterations of their fixation durations, revealing the complex interplay between language familiarity, reading fluency, and word recognition processes.

11.3 The Effects of the Previous Word N-1

In this section, we will investigate the effect of the frequency of the previous word which was found statistically significant for the fixation durations of the currently fixated word.

Figure 64

Plots of the frequency of the previous word N-1 on first fixation durations, gaze duration, and total reading time on word N for in reading Chinese



Three points can be emphasised with respect to the effect of the frequency of the previous word N-1. In this specific frequency range, from 0.002 to 6 (after power transformation), an overall rising trend becomes apparent. This means that as the frequency of the previous word increases within this range, the first fixation durations, gaze durations, and the total reading time on the currently fixated word also increase. In other words, there is a positive relationship between the frequency of the preceding word and the time spent on the currently read word.

This trend is significant because it highlights the sensitivity of these readers to variations in word frequency within this specific range. It suggests that as the linguistic context becomes more frequent, these readers tend to engage more deeply with the text, possibly to ensure comprehension or to process the information more thoroughly. With respect to different reading orders, when the frequency of the previous word surpasses the value of 6, the effects changes to facilitatory.

However, the non-linear findings suggest that reading comprehension is more complex. There may be points where the duration of the previous fixation has a particularly strong or weak influence on the target word. Regarding the first fixation duration, Chinese participants reading Chinese (L1) first had shorter times than when they read English (L2) first (the red line for Chinese first is lower than the blue line for English first). However, for gaze durations and total reading time, starting with English texts (blue line) resulted in shorter time compared to starting with Chinese (red line). This could be because reading English texts with similar content first aids faster word recognition and processing in Chinese for those more advanced in English. Our findings also reveal that the relationship between the duration a reader fixates on a previous word and its impact on the target word is not straightforwardly linear, indicating a more complex dynamic in reading processes.

11.4 The Effects of the Next Word N+1

In this section, we will examine and summarise the effect of the length and frequency of the next word which were found to be statistically significant for the fixation durations, gaze durations and total reading time of the currently fixated word in Figure 65 and Figure 66.

Figure 65

Plots of the length of the next word N+1 on first fixation durations, gaze duration, and total reading time on word N in reading Chinese

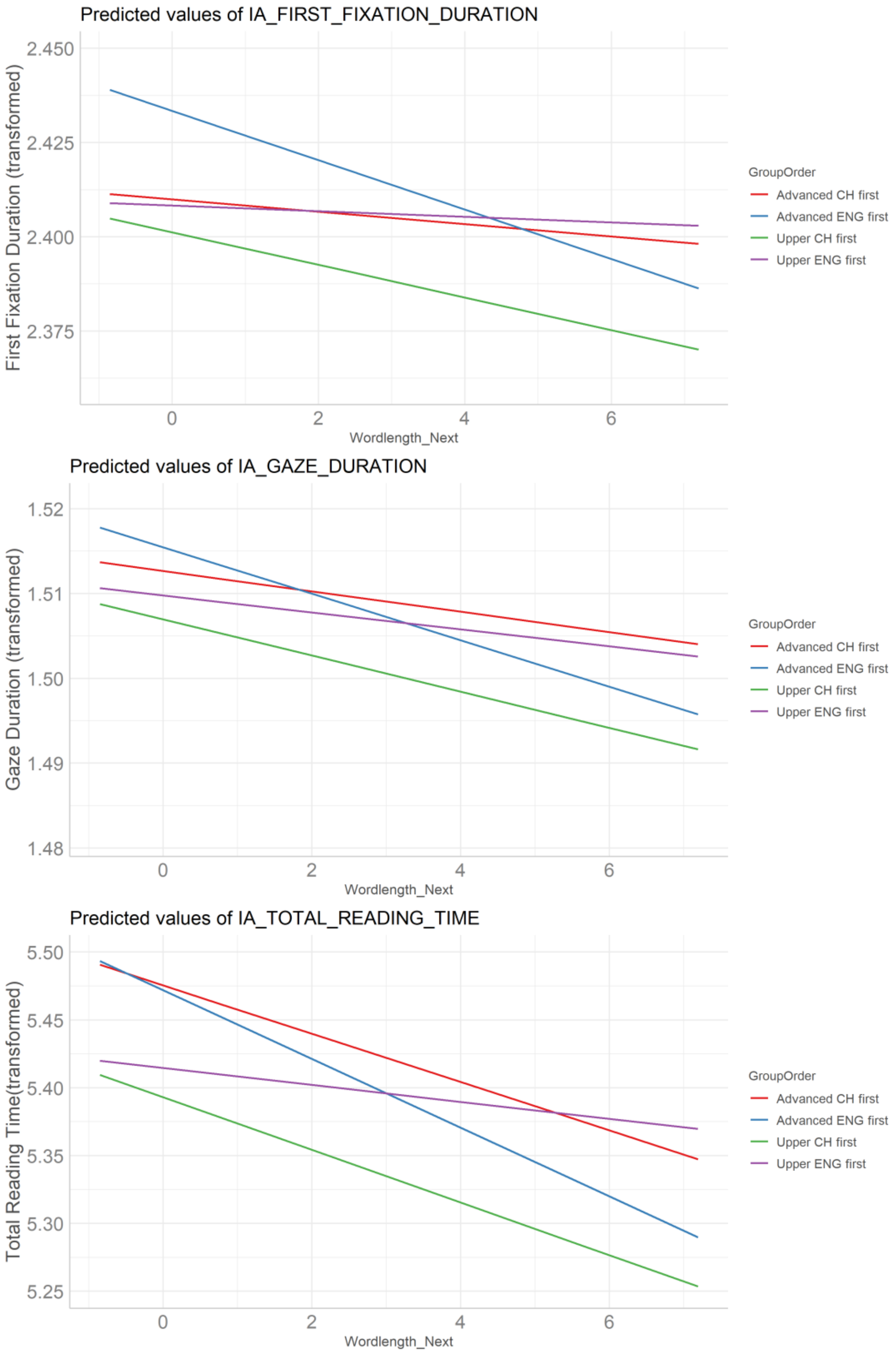
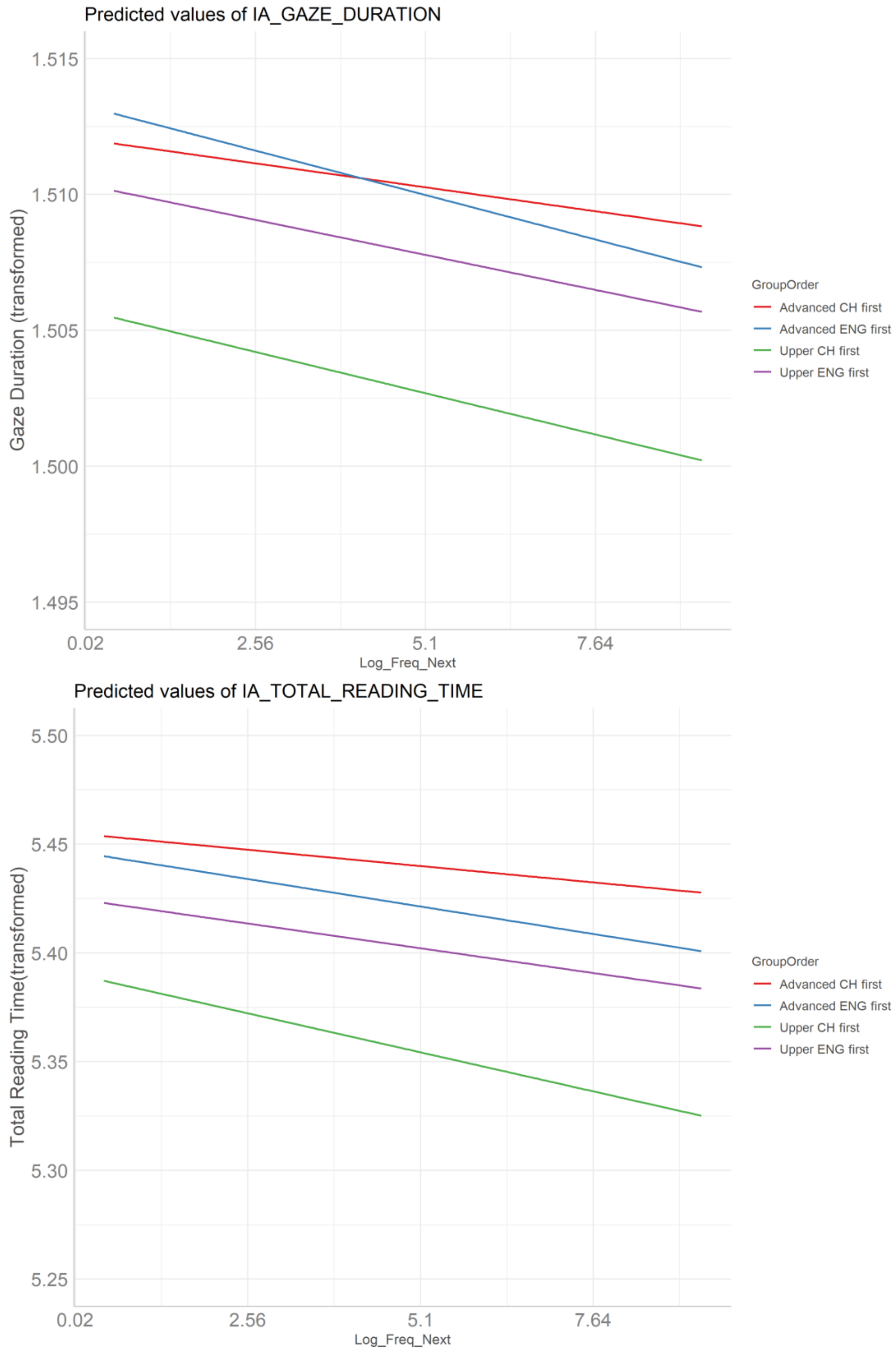


Figure 66

Plots of the frequency of the next word N+1on gaze durations, and total reading time on word N in reading Chinese



According to Figure 65, to the Upper Intermediate group, the length of the next word greatly affected their current reading. When these less proficient English readers started with Chinese texts, longer upcoming words resulted in shorter first fixation durations and overall reading time. On the other hand, the Advanced group showed a different pattern. They experienced a more significant impact from the length of the next word when they read English texts first and then Chinese. Consistent with our earlier results, we noted a more significant influence of the length of the subsequent word on fixation durations when individuals read Chinese as their native language (L1). This effect was particularly pronounced among the Upper Intermediate group, who, interestingly, had lower proficiency and less exposure to English as their second language (L2).

Essentially, this pattern reaffirms the idea that the reading process is intricately tied to language proficiency and familiarity. When readers engage with text in their native language (L1), they tend to be more sensitive to factors like length of Chinese words in L1 text. This increased sensitivity to word length in the Upper Intermediate group indicates that individuals may depend more on linguistic cues in their stronger language, even while reading in a language where they are less proficient and experienced.

According to the statistical modelling (results plotted in Figure 66), there were significant negative linear relationships between the frequency of the next word and the gaze durations and total reading time: as the frequency of the upcoming word gets higher, the gaze durations and total reading time on the currently fixated word get shorter. Comparing the fixation durations of two groups, same with what was reported in the previous sections, the Upper Intermediate group who read Chinese first had the shortest durations (see the green line).

11.5 Summary

A variety of empirical findings regarding both foveal and parafoveal processing have been presented, and the distinctions between two Chinese groups, differing in their levels of L2 proficiency and exposure, have been elucidated.

Our findings suggest that the order of reading can impact how L2 reading affects L1 reading habits, particularly in terms of word position. To our best knowledge, this finding is very new as no recorded previous study looked at or reported the effect of word position on fixation durations. Firstly, the less proficient group in L2 benefited more from directly reading Chinese. Secondly, the Upper Intermediate group in both reading orders had shorter fixation durations than the Advanced group. It implies that lower L2 reading proficiency and exposure lead to faster lexical processing in L1.

In their exploration of Chinese reading patterns, Li et al. (2014) reported a clear trend where an increase in the frequency of a given word (word N) was associated with a corresponding decrease in the gaze duration on that word. Additionally, they noted that shorter words tended to attract shorter gaze durations. In contrast, our investigation reveals a somewhat different pattern: while we observed a significant influence of word N's length on the total reading time for the currently fixated word, this effect was not mirrored in our gaze duration data. Rather, our findings specifically highlighted that gaze durations on word N were inversely related to word frequency, pointing towards a more complex interaction between word frequency and reading metrics than that reported by Li et al. (2014).

Moreover, Li et al. (2014) identified spillover effects from the frequency of the word preceding the currently fixated one (word N-1) to word N, as well as reverse spillover effects concerning word length. Their data suggested that gaze durations on word N were reduced when word N-1 was either more frequent or longer. Our results concur with the observation that increased frequency of the preceding word (word N-1) leads to shorter gaze durations, first fixation durations, and total reading times on the currently fixated word (word N). However, we found these relationships to be non-linear, indicating a more intricate interplay between the properties of consecutive words and the resultant eye movement patterns. Furthermore, our study expands the scope of analysis to include additional factors such as second language (L2) reading proficiency and the extent of exposure to the language. This broader analytical framework allows us to uncover further dimensions of the reading process in Chinese, offering insights into how these various elements interact to influence reading behaviours.

Our findings regarding the effect of frequency is similar to those found in English reading (e.g., Pollatsek et al., 2008; Rayner et al., 2004; White, 2008) and German reading (Kliegl et al., 2004; Kliegl et al., 2006). In addition to confirming established patterns regarding the influence of word frequency on reading dynamics, our study also sheds light on the multifaceted effects of second language proficiency and exposure, enriching the understanding of reading processes across different languages and linguistic backgrounds.

Chapter 12: Saccadic Landing Position

Grasping the 'where' and 'when' elements of eye movements while reading offers crucial understanding of the intricate cognitive, physiological, and perceptual process that play a role in the process of reading. The 'where' aspect refers to saccadic landing positions, which indicates the specific points on a line of text where the eyes momentarily stop during a saccade, or rapid eye movement. These landing positions are crucial for understanding the reading process as they indicate which words or parts of text are being fixated upon and processed by the reader.

While research has extensively focused on the 'when' aspect, investigating the durations of fixations and their relation to various linguistic and cognitive factors, the 'where' aspect has received comparatively less attention (Godfroid, 2019). However, understanding where the eyes move during reading helps us understand how visual information is acquired and integrated, and how this aspect of reading behaviour may differ across languages and individuals with varying language proficiency levels. By investigating the 'where' aspect, we can gain a more comprehensive understanding of the interplay between language-specific factors, such as orthographic differences, and the eye movement patterns observed during reading.

As outlined in the Method chapter (section 3.8), the Relative Landing Position (RLP) was utilised as a measure in this study to assess the initial landing position of participants' eyes on a word. In this research, the Relative Landing Position (RLP) was determined by comparing the location of the initial fixation[11] on a word with the word's

[11] It is pertinent to note that the term "initial fixation" in this study is defined as the first fixation on a word (IA). In the analysis of the data, we also examined the landing positions for words that received a

central point, which is the centre of the Interest Area (IA) - specifically the word being focused on in this study. In simpler terms, if the RLP value is greater than 0, it indicates that the initial landing position of the first fixation was to the left of the centre of the word. Conversely, if the RLP value is smaller than 0, it signifies that the initial landing position of the first fixation was to the right of the centre of the currently fixated word. To provide a better understanding of the calculation process and the relationship between the RLP and the actual initial landing positions of the eyes, let's consider two examples in Figure 67 and Figure 68.

In Figure 67, we present an example where the initial landing position is located between the two letters 'oo' in the word "floorboard". The midpoint or centre of the word "floorboard" is situated between the letter 'r' and the letter 'b'. In this specific case, we calculate the Relative Landing Position by subtracting the horizontal location of the initial landing position from the horizontal location of the centre/midpoint. The resulting value is greater than 0, so it indicates that the initial landing position is made to the left of the centre.

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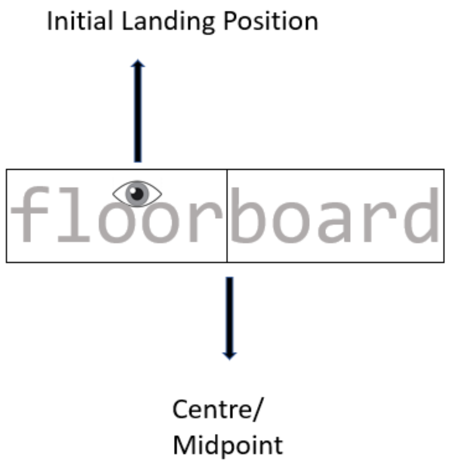
single fixation and observed no significant differences in the outcomes of both descriptive data analysis and modelling. Thus, this thesis presents the findings on landing positions informed by first fixations.

Figure 67

Initial landing position left of a word's centre illustrated



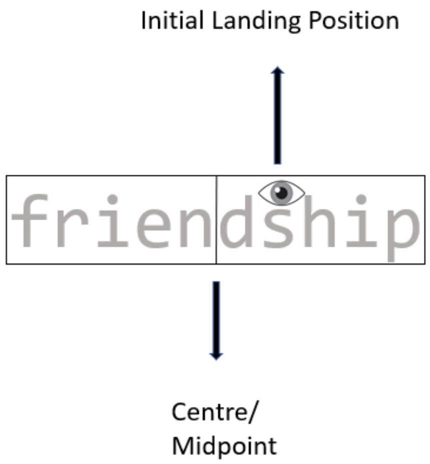
Relative Landing Position = Centre/Midpoint – Initial Landing Position

Relative Landing Position > 0 → Initial Landing Position to the left of the centre

In Figure 68, we present another example where the initial landing position is on letter ‘s’ in the word "friendship". The midpoint or centre of the word "friendship" is situated between the letter 'n' and the letter 'd'. In this specific case, we calculate the Relative Landing Position by subtracting the horizontal location of the initial landing position from the horizontal location of the centre/midpoint. The resulting value is smaller than 0 (negative), so it indicates that the initial landing position is made to the right of the centre.

Figure 68

Initial landing position right of a word's centre illustrated



Relative Landing Position = Centre/Midpoint – Initial Landing Position

Relative Landing Position <u>< 0</u> → **Initial Landing Position to the <u>Right</u> of the centre**

Previous eye-tracking studies conducted on alphabetic languages have revealed important insights into the oculomotor control during reading. These studies have shown that, when considering a constant launch site and word length, the distribution of saccadic landing positions on a word tends to follow a normal distribution pattern (McConkie et al., 1988). This fixed launch site helps researchers to study and understand the patterns of eye movements and landing positions during reading, especially when factors like word length remain constant. Within this distribution, the mean position can be construed as a measure reflecting the general effectiveness of saccadic targeting, with dispersion, commonly assessed through standard deviation, being associated with targeting precision. This is important as we can assume reasonably that such targeting depends on L2 proficiency and reading proficiency in particular.

In writing systems that are read from left to right, such as English, the typical location for saccadic eye movement landings tends to be a bit left of the centre of the word. This common landing spot is known as the Preferred Viewing Location (PVL) (Liversedge & Findlay, 2000; Rayner, 1979). It is important to note that the PVL tends to be closer to the centre for shorter words compared to longer ones. This indicates that readers exhibit a tendency to fixate their eyes slightly to the left of the centre of a word, with the degree of deviation influenced by the word's length.

It should be pointed out that the PVL should not be confused with the Optimal Viewing Position (OVP), which the initial landing position for the incoming saccade that is near the word centre and maximises the effective use of the reader's perceptual span. The perceptual span is asymmetrically skewed in the direction of reading, and the OVP allows readers to preview most characters in both the currently fixated word and the upcoming words. This preview facilitates more accurate saccade planning for upcoming words and reduces the effort required for word identification during fixation (Rayner, 2009a).

Adding to our understanding of these phenomena, it is essential to investigate the expectation of n+2 effects within the realm of Chinese reading. The continuous stream of logographic characters in Chinese, devoid of explicit word boundaries, propels readers to adopt a more integrative approach for effective word segmentation and processing. A pivotal study by Yan, Kliegl, Shu, et al. (2010) reveals that the perceptual span in Chinese reading is dynamically modulated by the frequency of the parafoveal word N+1, facilitating or hindering the preprocessing of word N+2 based on the ease of processing word N+1. This finding underscores that Chinese readers do not merely process the immediately fixated word (N) and the subsequent word (N+1) but are also capable of extracting and anticipating information from the second upcoming word (N+2) under conditions where word N+1 is easily processed. Such anticipatory processing significantly contributes to smoother reading transitions and enhanced comprehension, highlighting the unique cognitive and perceptual demands imposed by Chinese orthography. The exploration of n+2 effects in Chinese reading, therefore, reveals an essential adaptation of the oculomotor system, emphasising the intricate interplay between visual perception and cognitive processing in accommodating the language's specific demands. This adaptation is particularly facilitated by the narrow distribution of word length in Chinese, allowing for a clearer investigation of the dynamic interplay between visual, attentional, and lexical processes during natural reading, without the confounding factors present in alphabetic languages (Li et al., 2011; Yang et al., 2009).

The significance of the initial landing position within a word is further supported by the Inverted Optimal Viewing Position effect (Nuthmann et al., 2005), which demonstrates that landing positions closer to the word centre increase the likelihood of processing the word in a single fixation. Conversely, landing positions closer to the beginning or end of the word result in a greater dispersion of landing positions and lead to additional processing costs, such as prolonged fixation duration or the need for multiple fixations on the word (such as regressions) (Rayner et al., 1996). Therefore, accurate targeting of the word's centre as an optimal saccadic target confers advantages in terms of reading speed and effort, enhancing overall reading efficiency.

Considering the specific context of this study, it is anticipated that there will be notable differences in landing position choices between participants reading in Chinese and those reading in English. This is due to the distinct orthographic systems and linguistic characteristics of the two languages. Eye movement patterns in Chinese reading are still not fully understood, especially in terms of where Chinese readers direct their gaze during the reading process. Early research, which concentrated on the parafoveal preview benefit, did not consistently find a preview benefit within a word. Early research conducted by Yang and McConkie (1999) and Tsai and McConkie (2003) revealed that initial fixations on a word in reading Chinese were evenly distributed across all characters, resulting in a flat pattern for preview benefit curves.

However, more recent studies in eye-movement study of reading Chinese, such as the work by Yan, Kliegl, Richter, et al. (2010), have presented conflicting results compared to the earlier studies. They found that initial fixations on a word were more likely to occur at the beginning of the word, leading to a preview benefit curve that peaked at the word's beginning when multiple fixations were made on a word. This pattern aligned with findings from unspaced English reading and Japanese reading. Additionally, Yan et al. (2010) observed that when only one fixation was made on a word, the landing position tended to be at the centre of the word, like what has been found in English reading.

Furthermore, Yan et al. (2010) suggested a fixed distance strategy to explain patterns like skipping, duration of single fixations, and refixation trends in relation to word length and frequency. Nonetheless, they determined that this strategy by itself was insufficient to fully account for the observed patterns of eye movement guidance in Chinese reading.

The findings of Yan et al. (2010) were construed as indicating two mechanisms guiding eye movements in Chinese reading. The initial mechanism entails directing attention to the centre of a word, provided that the word boundary can be ascertained through parafoveal vision. The second mechanism occurs when the word boundary cannot be determined parafoveally, leading to saccades targeting the beginning of the word. While this interpretation provides a plausible explanation for the observed data, an alternative explanation is possible.

Yan et al. (2010) highlighted the enhanced efficiency in word processing when fixations are positioned at the central region of the word. Consequently, if a fixation is centred within a Chinese word, the processing of all characters within that word is facilitated, obviating the necessity for subsequent saccades to target other characters within the same word. In essence, precise knowledge of a word's exact boundary may not be imperative for readers to guide a saccade towards its centre. The occurrence of a chance fixation at the word's centre may eliminate the need for an additional fixation on the same word. Consequently, the observed disparities in data patterns between preview benefit curves for single fixations and initial fixations of multiple fixations do not unequivocally substantiate the assertion that Chinese readers can occasionally discern the word boundary parafoveally and direct their gaze to the word's centre under such circumstances.

A recent study by Xia et al. (2023) revealed that in Chinese reading, readers don't have specific Preferred Viewing Locations (PVLs), contrary to the default-targeting hypothesis that posits fixed focal points in text. This was confirmed through two experiments, which demonstrated that readers' eye movements do not consistently target the centres of words or other PVLs, even with knowledge of sentence structure. The study found that the dynamic-adjustment model more accurately describes these findings, indicating that eye movements in Chinese reading are influenced more by parafoveal processing than by predetermined PVLs, thus revising previous beliefs about PVLs in languages like Chinese.

Furthermore, as second language (L2) readers develop their proficiency in the target language and gain exposure to the L2 writing system, it is expected that their saccadic patterns will gradually align with those of native readers in their L1. This alignment signifies the process of L2 readers acquiring optimal landing positions similar to those of proficient native readers.

In this chapter, we will present five main sections related to the landing positions in English and Chinese reading studies. The first two sections focus on the landing positions in the English reading study. In the first section, we provide a descriptive data analysis to visualise the results of the landing positions in the English reading study. This analysis aims to highlight the similarities and differences between the two groups of Chinese participants as second language (L2) readers and native English readers. The second section presents the results of inferential analysis, examining the impact of word-level effects (such as word length and frequency) and order effect (such as word and story order) on the positions for both L2 readers and native English readers when reading English texts.

Moving on to the Chinese reading study, section 3 presents the main distributions of landing positions observed in Chinese participants (divided into two groups) when reading Chinese texts. This section provides an overview of the landing position patterns found in the Chinese reading study. In section 4, we employ statistical modelling techniques and visual plots to analyse the main effects influencing the variance of landing positions during Chinese reading.

Finally, in section 5, we engage in discussions that encompass the findings and results obtained from both the English and Chinese reading studies. This section aims to synthesise and interpret the observed patterns and.

12.1 Descriptive Analysis of the English Reading Study

To investigate the eye movement patterns, especially the initial fixation points on words (landing positions), we conducted detailed analyses comparing native English readers and Chinese participants. Our study had two main aims: 1) to explore the basic patterns of landing positions, particularly focusing on how word length influences these positions, across three distinct groups (native English readers as a control, and two groups of Chinese readers with different English proficiency); 2) to examine the effect of reading texts in different orders on the landing positions for the Chinese groups.

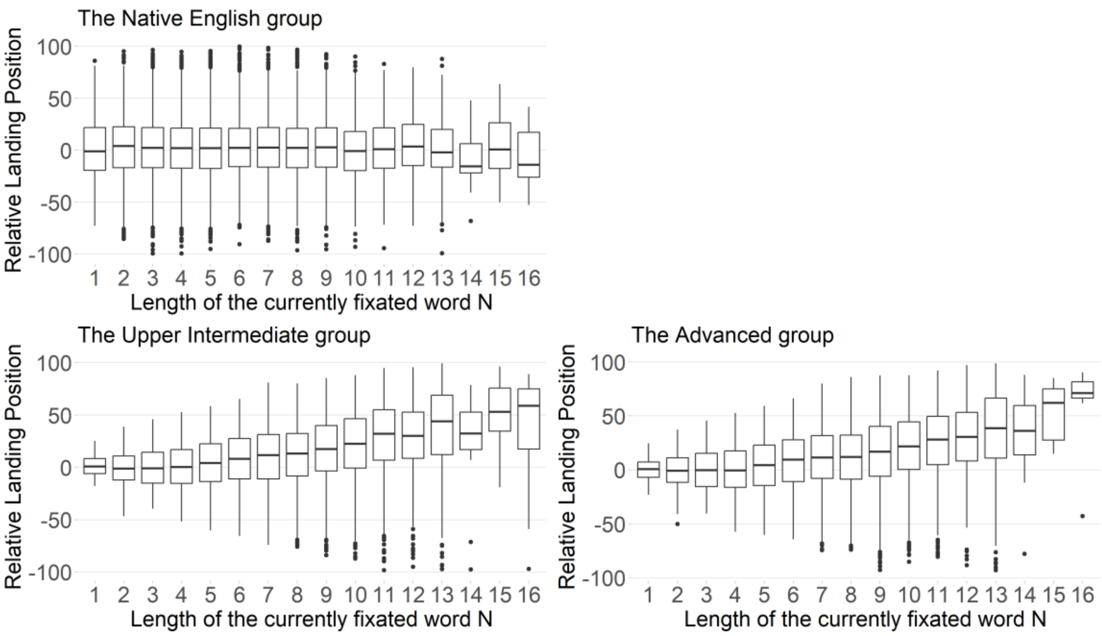
The second goal is crucial as it offers insights into saccadic programming in bilingual reading. Understanding how the order of text exposure affects eye movements and landing positions can reveal how bilingual readers adjust their saccadic behaviour when shifting between languages. This contributes significantly to our understanding of the cognitive and neurological mechanisms underlying bilingual saccadic control and reading strategies. These analyses contribute to our understanding of the factors influencing landing positions in reading and shed light on the similarities and differences between native and non-native readers in their eye movement patterns.

12.1.1 Relative Landing Positions of Three Groups

Figure 69 illustrates the main distributions of relative landing positions among three participant groups in reading English, with a focus on how relative landing positions vary with the length of the currently fixated word.

Figure 69

Box plots of the relations between length of the currently fixated word N and the Relative Landing Positions of two Chinese groups and the native group



The boxplots represent the distributions of relative landing positions for three groups of readers, x-axis representing the length of the currently fixated word and the y-axis represents the relative landing position of the first fixation on a given word.

Firstly, for native readers of English, there is only a minimal variation in median values of relative landing positions as the length of the currently fixated word increases. Secondly, the dispersion of relative landing positions also remains relatively consistent across different word lengths.

Notably, discernible differences emerge in the landing positions of the two Chinese groups (the Upper Intermediate group in the lower left and the Advanced group in the lower right). Specifically, as the length of the currently fixated word (N) increases, the landing positions of the two Chinese groups tend to shift further away from the centre of the word: the landing positions progressively deviate towards the beginning of the word as the length of that word increases. In sum, Chinese participants show differences in landing positions compared to native readers.

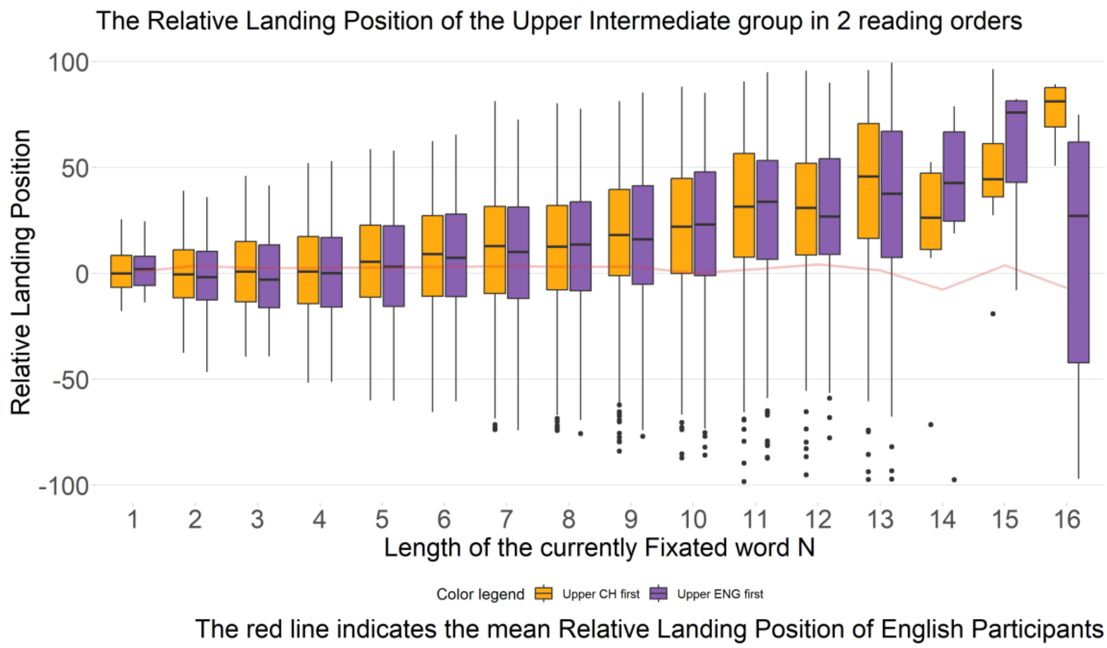
The second difference between the two Chinese groups and the native English participants regarding the relative landing position is in terms of dispersion. While there are only minimal changes in “scatter” of landing position for native readers, L2 readers show more variations with the increase of word length. As L2 readers typically have more limited exposure to and experience with the language, it is reasonable to expect that their saccadic targeting accuracy may be affected (cf. McConkie et al., 1988). The dispersion in their landing positions could be attributed to challenges in effectively integrating visual information, making accurate predictions, and executing precise eye movements while reading in a second language.

12.1.2 Landing Position, Saccadic Planning, and Order Effect in L2 Reading

Figure 70 presents a visual representation of the distributions of relative landing positions for less proficient L2 readers (Upper Intermediate group) in reading English, separated by language reading order (Chinese or English first). The yellow boxes in the figure represent participants who read English first, while the purple boxes indicate the relative landing positions for participants who first read Chinese texts.

Figure 70

The relationship between the length of the currently fixated word N and the relative landing positions of the Upper Intermediate group in two reading orders



Note. The red line indicates the mean values of the relative landing positions of the English participants as the native group.

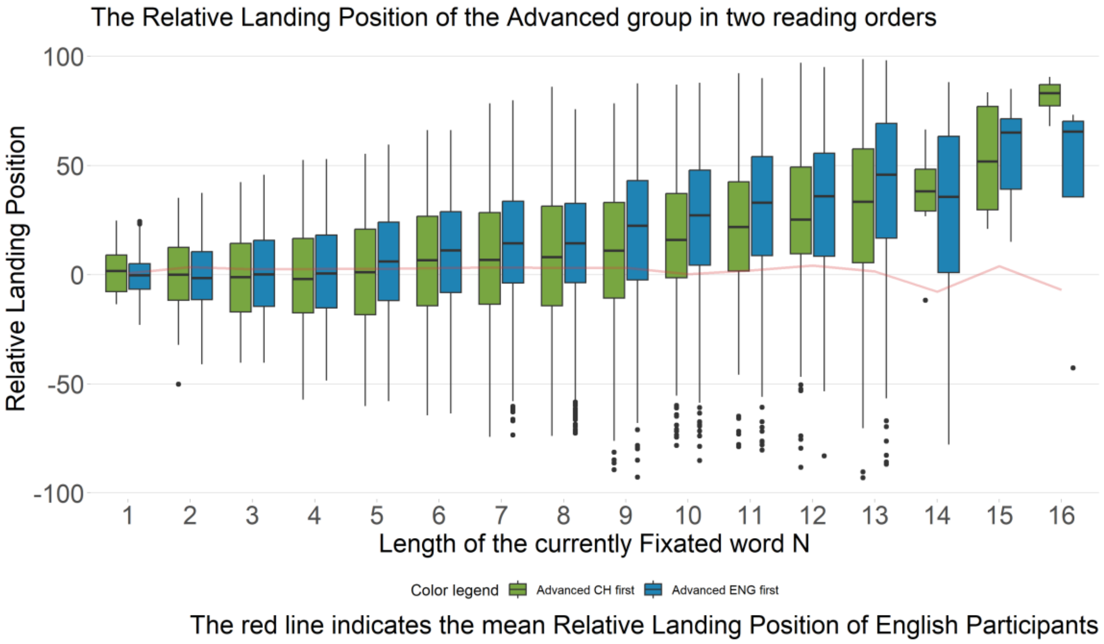
As the length of the word increases, there is a corresponding shift in the initial landing position: as the word length increases, the initial landing position moves to the beginning of the word.

The median values of the relative landing positions differ between the two reading orders across different word lengths (horizontal black lines in the middle of the box). We see some variation in this central tendency of the landing position given the language reading order.

Figure 71 below presents the distributions of relative landing positions in reading English for participants in the Advanced group based on the length of the currently fixated word and two different reading orders (green boxes indicate reading Chinese first and blue boxes indicate reading English first). Note that the red line indicates the mean values of the relative landing positions of the English participants as the native group.

Figure 71

The relationship between the length of the currently fixated word N and the relative landing positions of the Advanced group in two reading orders



Like the Upper Intermediate group, the Advanced group's fixation points shifted noticeably with the increase in word length. In both language orders, we see more pronounced variations compared to the native group (as indicated by the red line in the plot). This suggests that the Advanced group's eye movements were more influenced by the word length than those of the native readers.

12.2 Statistical Modelling the Relative Landing Positions Data in Reading English

In this section, we are going to analyse the impact of English proficiency and L2 exposure, and word-level properties on the relative landing positions using a linear mixed-effects model (Baayen, Davidson, & Bates, 2008). Models were fitted using the lmer function from the lme4 package (Version 1.1-26, Bates, Mächler, Bolker, & Walker, 2014) in the R Environment for Statistical Computing (Version 3.3.1, Rstudio

Team, 2020). In line with the modelling approach discussed in previous chapters, we conducted a series of hierarchical regressions to examine the relationships between landing positions and various factors, including word-level characteristics and language proficiency levels, within the three participant groups and two reading orders. Through comparing and evaluating multiple models, we have identified the most parsimonious model, which we will report.

A complete report about the results of this model can be found in Appendix 12A.

The specification of the final best model is:

```
RelativeLandPos ~
  GroupOrder / (
  poly(Wordlength_N, 2) +
  poly(Wordlength_Prev, 2) +
  poly(Wordlength_Next, 2)) +
  (1 | Participant_ID) +
  (1 | Story_ID) +
  (1 | Word_ID)
```

The total explained variance (R^2) of the model is approximately 18%.

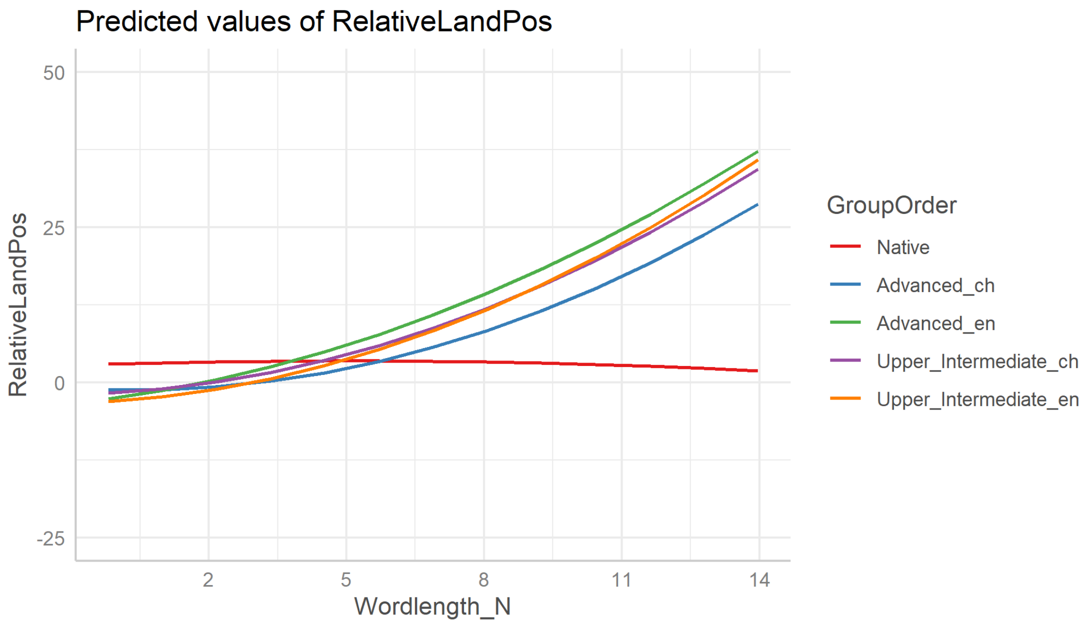
To provide a visual representation of significant effects across the participant groups, we have created Figure 72 to Figure 74. These figures serve to further illustrate the observed impacts and highlight any discernible patterns among the groups. By presenting these visualisations, we aim to enhance the understanding of how the identified significant effects influence the relative landing positions in each participant group.

12.2.1 The Effect of the Length of Word N

The first independent variable at the word level that was found statistically significant is the length of the currently fixated word. presented in Figure 72.

Figure 72

The effect of the length of the currently fixated word N on the relative landing positions on word N for two Chinese groups with different reading orders compared to the native group



The x-axis represents the length (number of letters) of the currently fixated word ranging from 1 to 14. The y-axis represents the relative landing positions. The groups and language orders (for Chinese L1 readers) are presented in different colours.

An intriguing finding emerges from Figure 72, indicating that language order effect is found statistically significant for the Advanced group but not for Upper Intermediate group. This result suggests that the reading order has a more pronounced effect on the eye-movement behaviour of the Advanced group compared to the Upper Intermediate group.

The overlapping lines of the Upper Intermediate group in both reading orders suggest that this group is less affected by the variation in reading order when it comes to the initial landing positions.

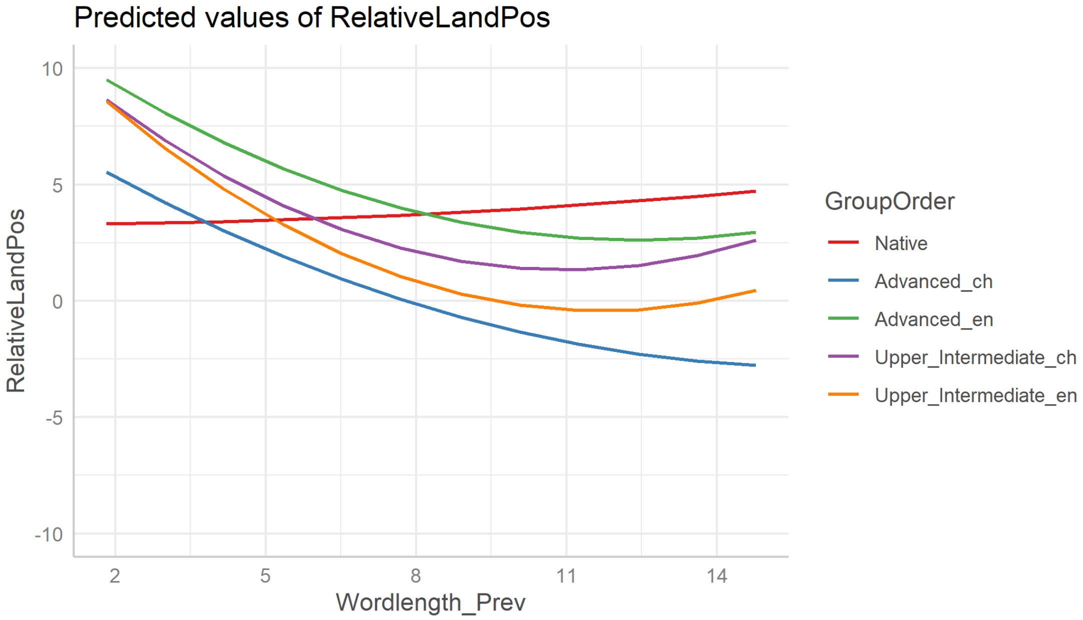
The findings in Appendix 12A reveal that word length significantly affected the landing positions for the two Chinese groups in both reading orders, unlike for the native group, showing a clear difference in how word length influences their reading. In contrast, the lack of a significant influence of word length on the relative landing positions of the native group suggests that native English readers show no variation in landing position with word length. This was obvious from descriptive analysis too and may indicate crucial differences between highly optimised English L1 reading vs. L2 reading of groups that differ in proficiency and order in which they read English texts.

12.2.2 The Effect of the Length of Word N-1

The relations between the length of the previously fixated word N and the relative landing position on the currently fixated word in reading English is presented in Figure 73.

Figure 73

The effect of the length of the previous word N-1 on the relative landing positions on word N for two Chinese groups with different reading orders compared to the native group



The modelling results show no significant effect for the native group, and a similar nonlinear pattern for four groups of Chinese readers, showing earlier landing if N-1 is shorter.

The plot reveals a declining trend, indicating that as the length of the previous fixated word increases, the initial landing positions of the Chinese participants in both groups tend to be closer to the centre of the currently fixated words. That shift towards fixating closer to the centre of the words aligns with the Optimal Viewing Position.

These findings indicate that the length of the previous fixated word N-1 has a significant impact on the saccadic planning and targeting of the Chinese participants. The observed shift towards the centre of the words suggests a strategic adjustment in eye-movement behaviour, potentially reflecting the participants' efforts to optimise their reading efficiency and accuracy in response to the characteristics of the preceding word.

Another noteworthy finding is the larger difference observed between the more Advanced Chinese L2 readers as affected by different language reading orders (green and blue lines). Lines representing different language reading orders for the Upper Intermediate group (purple and orange lines) are close to one another, while those for the Advanced group show significant difference.

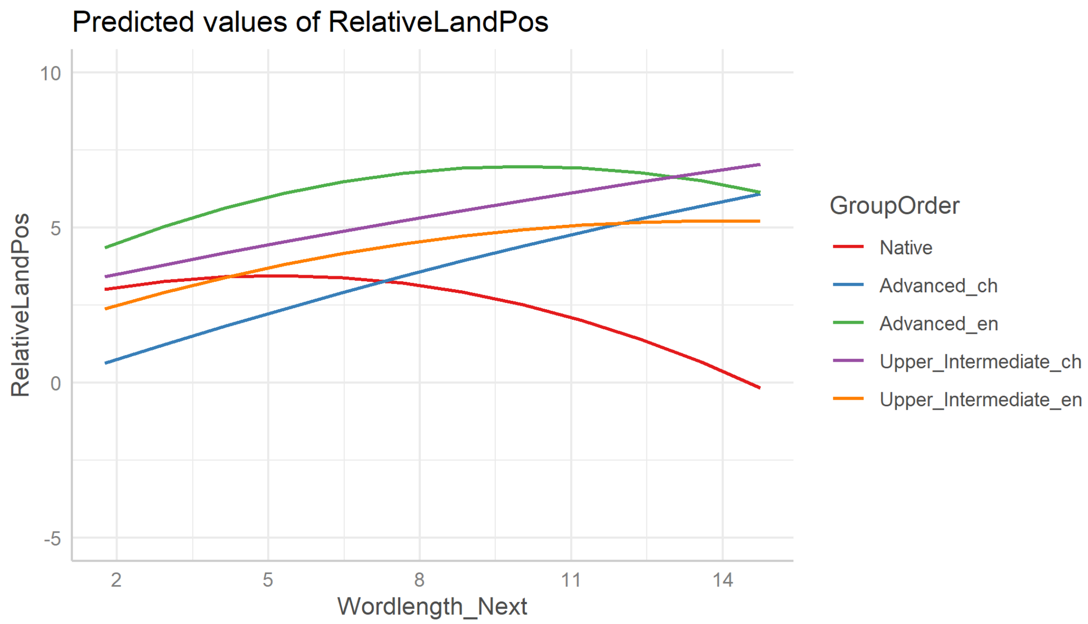
This discrepancy suggests that the effect of language reading order is more pronounced for Chinese participants with higher English proficiency and more exposure. In other words, the distinct patterns observed in the Advanced group indicate that their eye-movement strategies and saccadic planning are more sensitive to the differences in reading order, compared to the Upper Intermediate group.

12.2.3 The Effect of the Length of Word N+1

The relations between the length of the next fixated word N+1 and the relative landing position on the word N while reading English is presented in Figure 74.

Figure 74

The effect of the length of the next word N+1 on the relative landing positions on word N for two Chinese groups with different reading orders compared to the native group



The Native group (red line) reveals that as the word length of the upcoming word increases, the initial landing position on the currently fixated word tends to move closer to the centre from the left side.

This pattern indicates that native English readers exhibit a consistent adjustment in their eye movements based on the length of the upcoming word. The observed trend suggests a strategic adaptation in saccadic planning, where readers aim to optimise their fixation positions by adjusting the initial landing positions based on the characteristics of the subsequent word.

12.3 Descriptive Analysis of the Chinese Reading Study

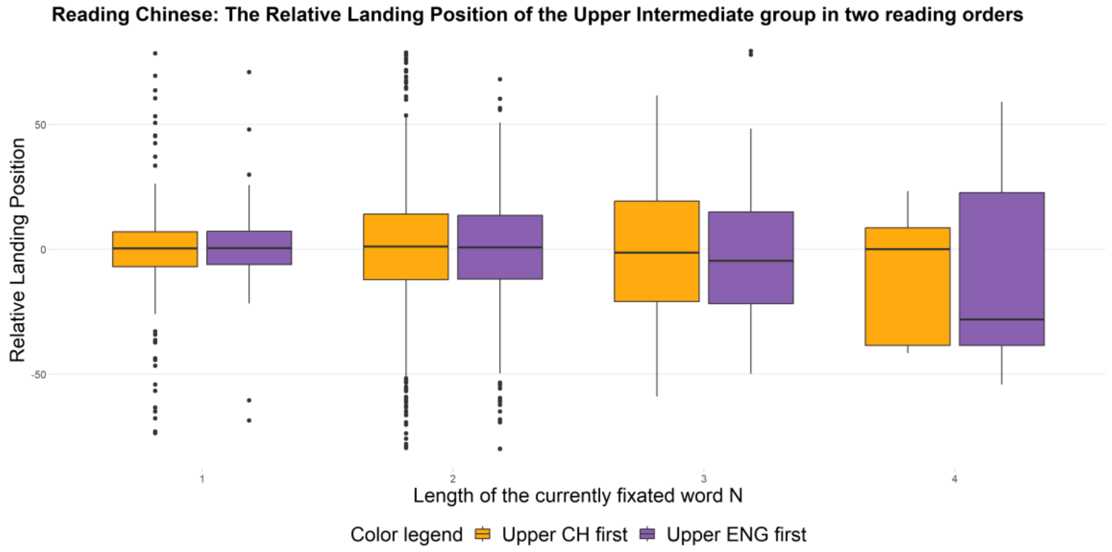
In this section, we will begin with the outcomes from our analysis of reading Chinese texts, highlighting the key differences in eye movement patterns between reading in Chinese as native language, and in English as their second language. Note that in the analysis of the Chinese reading study, the Chinese participants were divided into two groups based on their language proficiency and duration of stay in the UK. We have adopted the same grouping approach in the Chinese reading study on initial landing positions to examine the potential influence of L2 reading proficiency and exposure on the eye-movement patterns during L1 reading.

12.3.1 Within Group Comparisons

In this section, we will compare the differences we observed in the Relative Landing Position of the Upper Intermediate group and the Advanced group in both reading orders as shown in Figure 75 and Figure 76.

Figure 75

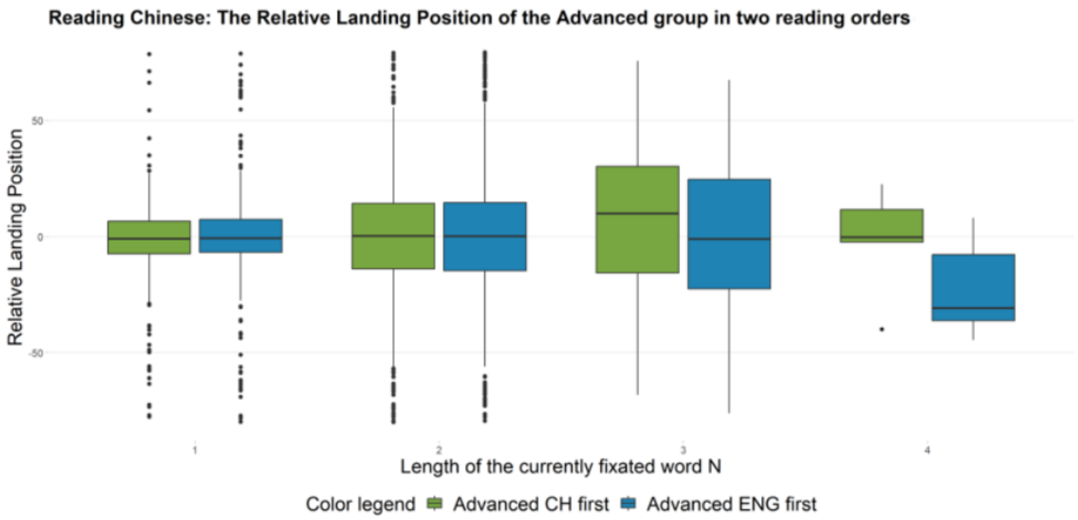
The relationship between the length of the currently fixated word N and the relative landing positions of the Upper Intermediate group in reading Chinese



Note. In the Chinese reading study, yellow boxes represent the eye movement landing positions of the Upper Intermediate group when they read Chinese first. Purple boxes show these positions for the same group when they read English first. In Figure 75, the 0 represents the midpoint between two Chinese characters, denoting the space that separates them.

Figure 76

The relationship between the length of the currently fixated word N and the relative landing positions of the Advanced group in reading Chinese



Note. In the study, green boxes show the Advanced group's landing positions when reading Chinese first, and blue boxes indicate their positions when reading English first.

In the above two figures, it was noted that Chinese readers with upper intermediate proficiency exhibit fixation points on words that align closely with those of native English speakers for words ranging from one to three characters in length. For both groups, the tendency is to focus their gaze towards the middle of these shorter words. However, a significant variation in this behaviour emerges when the words extend to four characters. At this length, the eye movement patterns of the two groups differ notably.

To explain why there might be a difference when the word length reaches four characters, it could be related to the cognitive processing involved in reading. In languages like English, longer words might require more effort to identify, leading to a shift in the optimal viewing position towards the beginning of the word to facilitate easier word recognition. In contrast, Chinese characters can contain meaning in each character, and a four-character word might represent a more complex idea or phrase. As a result, Chinese readers might adjust their fixation strategies to accommodate for the increased processing demand, which could lead to more variability in where their gaze lands within the word.

Participants who read Chinese first tended to make initial landing positions more to the right side of the Chinese word compared to the centre location of the word, while those who read English first tended to make more initial landing positions to the left side of the central location of the Chinese word. These findings highlight the influence of L2 experience on the eye-movement patterns of participants and demonstrate the differential effects of reading order on the location of initial landing positions.

The data shows that for shorter words of two or three characters, the range of starting points where Chinese-first language readers look at the word is broader than for those who read English first. This means that Chinese-first readers do not always start looking at the same part of the word, while those familiar with English tend to start in more predictable places. Additionally, for one or two-character words, Chinese-first readers usually begin reading to the left side of the word.

Interestingly, for longer words of three or four characters, those who have read English before tending to look right at the middle of the word more consistently. This change suggests that reading English might influence how readers approach longer Chinese words, making their initial gaze more centered.

12.3.2 Comparisons Across Groups

In this section, we aim to compare the distributions of the Relative Landing Positions of two Chinese groups in two reading orders.

The study found that the Advanced group's starting gaze points vary more compared to those in the Upper Intermediate group. This means that the Advanced group, despite being more proficient in English, does not land their gaze as consistently in the centre of the word they are looking at in Chinese. In simpler terms, those with less English proficiency and less exposure to English seem to focus their gaze more steadily on the centre of the Chinese words they read.

The data also shows that for one to three-character words, the range of starting gaze points is narrower, indicating more consistent reading patterns. However, when the words get longer, the range widens for the Upper Intermediate group who have read English before, suggesting that their reading patterns become less consistent with longer Chinese words.

12.4 Statistical Modelling the Relative Landing Positions Data in Reading Chinese

In this section, we will model the effect of English proficiency and L2 exposure, and word-level properties on the relative landing positions in reading Chinese. Models were fitted using the lmer function from the lme4 package (Version 1.1-26, Bates, Mächler, Bolker, & Walker, 2014) in the R Environment for Statistical Computing (Version 3.3.1, Rstudio Team, 2020). Here too, we fitted a series of hierarchical regressions to draw inferences across possible relationships both at the word-level, language proficiency, and language order. A series of models were run and compared, and below is the most parsimonious model reported. Note that non-significant predictors were disregarded from the final model.

A complete report about the results of this model can be found in Appendix 12B.

```
RelativeLandPos ~
  GroupOrder / (
  poly(Wordlength_Next, 2) +
  poly(Fre_log_Prev, 3) +
  poly(Fre_log_Next, 3)) +
  (1 | Participant_ID) +
  (1 | Story_ID) +
  (1 | Word_ID)
```

The results of the hierarchical regression model revealed that the model's total explained variance of the relative landing position was 21% (i.e., R2 = 0.21).

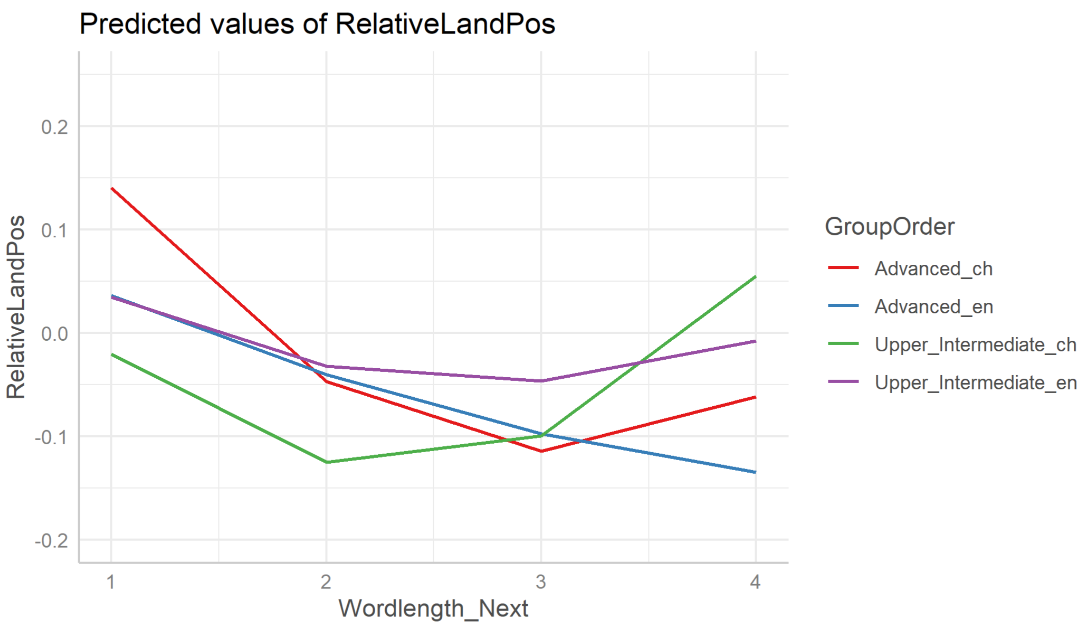
The fixed effects that were found to be statistically significant, as determined by the test statistic are visualised from Figure 77 to Figure 79.

12.4.1 The Effect of the Length of Word N+1

In this section, we focus on visualising the relationships between the length of the next fixated word (N+1) and the relative landing positions on word N for the two groups of Chinese participants when reading Chinese, also taking into account different reading orders. By examining these relationships, we aim to gain insights into how the upcoming word length influences the initial landing positions on the currently fixated word for Chinese readers.

Figure 77

The effect of the length of the next word N+1 on the relative landing positions on word N for two Chinese groups with different reading orders in reading Chinese



Note. Red line represents the Advanced group reading Chinese first, and blue line for English first. Two other lines show the Upper Intermediate group's reading in both reading orders.

The modelling results indicate that when both the Advanced and Upper Intermediate groups read Chinese before English, the length of the next word they are going to read affects where they first look at the current word. This is a significant finding because it shows that the word length in Chinese influences their eye movements.

On the other hand, when participants begin with reading English, this effect is not observed. This absence could imply that reading English, which is their second language (L2), has impacted their reading strategy in a way that they no longer rely on the length of the next word in Chinese to guide their initial gaze. This might be because reading English, which typically involves different eye movement patterns due to its alphabetic nature and the structure of English words, could alter their reading behaviour even when they switch to reading Chinese.

In other words, the prior experience of reading in English could have adjusted their reading habits, making them less sensitive to the cues they would otherwise use in Chinese, such as the length of the upcoming word. This suggests a sort of "priming" effect where the initial language read sets the stage for how subsequent reading is processed, even if the subsequent reading is in a different language with a different script and spatial structure.

Next, the red line in Figure 77, representing Advanced group reading Chinese first, as the upcoming word becomes longer (from one to three characters), the initial landing positions tend to move from the left side of the word towards the middle, and then towards the right side of the word. However, when the word length increases to four characters, the initial landing positions tend to shift back closer to the centre.

The study shows that for the Upper Intermediate group, which is less skilled in the second language (L2), there is a particular way they move their eyes when reading Chinese. When the word they are going to read next has only two characters, they start looking more towards the right side of the current word. But, if the next word is longer, like three or four characters, they begin to look more towards the middle or even the left side of the current word. This is different from the more skilled Advanced group.

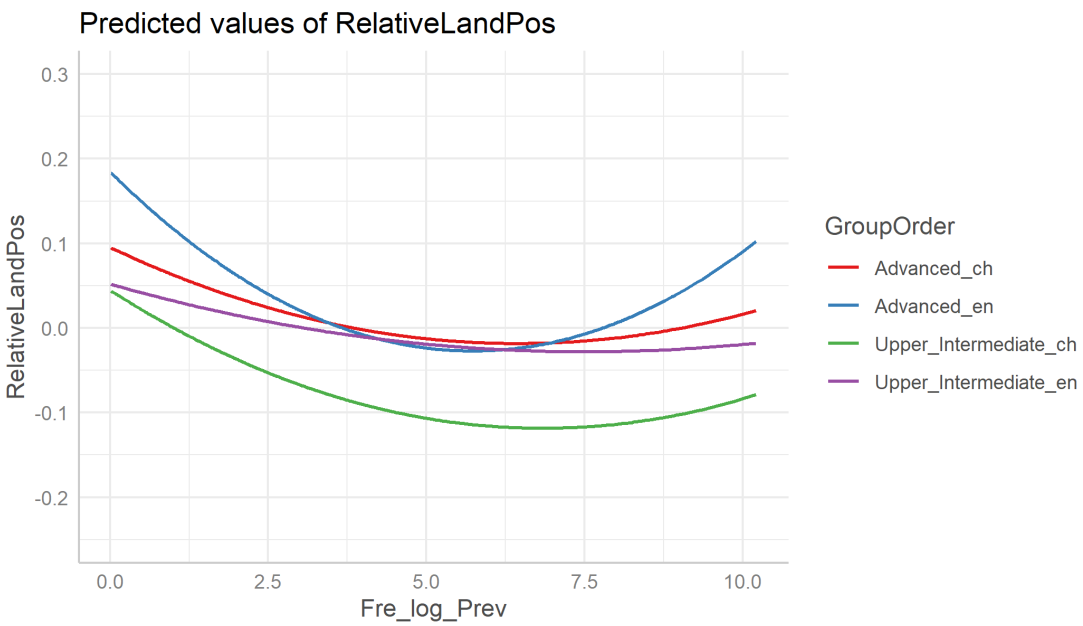
A simpler way to say this is that people who are not as good at English yet start to look to the left side of Chinese words sooner as the words get longer, compared to those who are better at English. One reason for this might be that those in the Upper Intermediate group rely more on context clues from the entire sentence to understand and predict the text, causing them to shift their gaze earlier.

12.4.2 The Effect of the Frequency of Word N-1

According to the modelling results, the frequency of the previously fixated word N-1 is also found statistically significant to predict the variance of the Relative Landing Position (initial landing position).

Figure 78

The effect of the frequency of the previous word N-1 on the relative landing positions on word N for two Chinese groups with different reading orders in reading Chinese



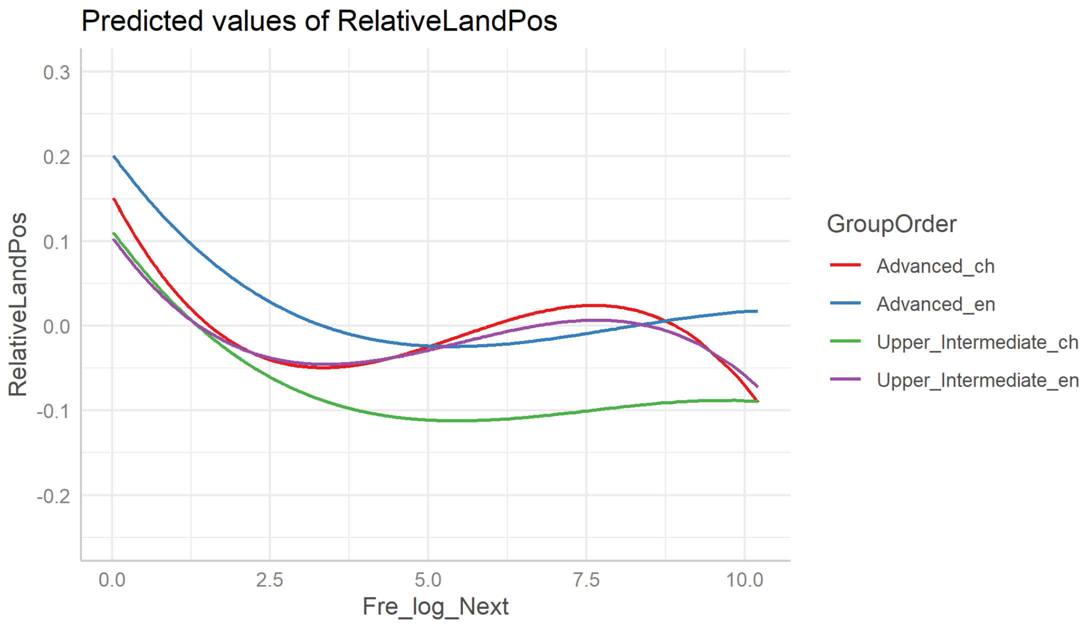
According to modelling results, the relationships between the frequency of the previous word and the initial landing position on the currently fixated word is only found significant for Advanced group when English texts were first to read. As the blue line in Figure 78 indicates, there is a statistically significant negative and nonlinear relationship between the frequency of the previous word and the initial landing positions on the currently fixated word: as the frequency of the previous word increases, the initial landing position on the currently fixated word tended to more towards the centre of the word. However, as the frequency of the previous word increases beyond 5, the initial landing positions on the currently fixated word tended to be made to the left of the centre of the word. Interestingly, we observe a similar pattern in the Upper Intermediate group when they read Chinese first, as the green line in Figure 78 indicates even though it is not statistically significant.

12.4.3 The Effect of the Frequency of Word N+1

Not only the frequency of the previously fixated word but also the frequency of the next word was found statistically significant to predict the variance of the relative landing positions in reading Chinese.

Figure 79

The effect of the frequency of the next word N+1 on the relative landing positions on word N for two Chinese groups with different reading orders in reading Chinese



The modelling results show that the relationship between the frequency of the next word N+1 and the initial landing position on the currently fixated word is statistically significant for the Advanced group, but only when they read Chinese first. As the red line in Figure 79 presents, the initial landing position start moving more towards to the middle of the currently fixated word from the left side and then to the right as the frequency of the next word increases. For the most frequent words, typical landing position moves back towards the centre of the word.

Additionally, there is a comparable pattern for the Upper Intermediate group when they read Chinese first, as shown by the green line, and for the Advanced group when they read English first, shown by the blue line.

This could be because more familiar words are processed faster, so the eyes do not need to start as far to the left to read the entire word. As readers become more confident in predicting the upcoming word due to its high frequency, their gaze drifts towards the centre, suggesting a more efficient reading process. This efficiency is seen when they read their first language, Chinese, indicating that their reading habits in their native language are influencing how they read based on word frequency.

12.5 Discussion

In this section, we aim to recap and list all the main findings in this chapter about landing positions in the English and Chinese studies, firstly within each study respectively, then new results across two studies will be presented.

12.5.1 English Reading Study

An ongoing scholarly discourse centres around the determination of whether saccadic targeting is solely dictated by the visual attributes of the textual content or if cognitive influences play a role. Earlier investigations posit that readers are guided by visual cues such as word length, including spaces (McConkie et al., 1988; Radach et al., 2007; Reichle et al., 1998a). A more contemporary perspective suggests that readers direct their gaze toward the segment of an upcoming word that is most pertinent or salient, reflecting their current cognitive processing state of the text (Bicknell et al., 2020; Rayner et al., 1980). The analysis of our data revealed a notable difference in the dispersion of landing positions between the two Chinese groups, as second language (L2) readers, and the native English group. Specifically, the L2 readers exhibited a significantly greater dispersion, indicating less accuracy in saccadic targeting compared to the native group. However, our results suggest that with increased experience in L2 reading the accuracy of motor control increases too.

This observation indicates that for Chinese readers, regardless of whether they read in Chinese or English first, there is a clear pattern in how they look at words based on their length. When the word they are currently focusing on is longer, they start reading closer to the beginning of the word. This trend reflects a consistent way in which the length of a word influences their eye movements, particularly when they are reading English as their second language (L2).

This finding aligns with previous research in the field of psycholinguistics and eye movement studies. Earlier studies have shown that readers, in general, adjust their initial fixation position based on the length of the word - the Optimal Viewing Position (OVP) effect. For shorter words, readers tend to fixate near the centre, as it allows them to see the entire word easily. However, for longer words, fixating at the centre would not provide a clear view of the entire word, especially in languages with alphabetic scripts like English. Thus, readers shift their gaze towards the beginning of longer words to facilitate easier processing and comprehension.

This pattern observed in Chinese readers reading English suggests that these OVP dynamics are at play even when reading a second language that has a different script and linguistic structure from their native language. It demonstrates the adaptability of the eye movement system in response to the structural characteristics of different languages and supports the theory that word length is a crucial factor in guiding visual attention during reading.

Secondly, we identified that word length of word N-1, N and N+1 all had statistically significant relationships with the initial landing position. The findings suggest that word length plays a significant role in predicting the variance of the initial landing position in reading English, for both L1 and L2 groups.

These results suggest systematic adjustments in eye movement patterns based on word length, with longer words leading to a preference for left-sided initial landing positions. Moreover, when the preceding word (N-1) is long, Chinese readers show an inclination to adjust their initial landing positions towards the middle of the word.

Chinese participants showed tendency to shift their initial landing positions from the centre of the word towards the left of the centre as the N+1 word length increased. This finding suggests a different reading strategy employed by Chinese participants when processing English texts compared to native English speakers. These results emphasise the importance of considering language-specific factors in understanding eye movements during reading across different languages.

12.5.2 Chinese Reading Study

Given the absence of spaces between words and the inherent ambiguity regarding word boundaries in the Chinese language (Li et al., 2009), the question arises: how do Chinese readers determine their saccade targets during reading?

Research conducted on eye movements during the reading of alphabetic languages has yielded valuable insights into the fixation patterns within words and the consequential impact on fixation durations. Within the realm of alphabetic languages, a prevalent conjecture is the word-based nature of saccade targeting, wherein each saccade is presumed to be directed towards placing the eyes precisely on a designated word (Radach et al., 2004). Consequently, the spatial aspect of eye movement control in reading can be analysed a structured, step-by-step manner (McConkie et al., 1994). Initially, readers are tasked with the dual processes of identifying the word that will serve as the focal point for the upcoming saccade and subsequently ascertaining the exact position within the selected word where the eyes will alight. The latter inquiry relates to the distribution of fixation positions within words. It is noteworthy that fixation points exhibit a proclivity to manifest slightly to the left of the word centre, a phenomenon commonly referred to as the "preferred viewing location." (PVL) (Rayner, 1979). The identification of such a PVL is often cited as a critical piece of evidence supporting the concept of word-based eye guidance in alphabetic script reading (see S.-N. Yang & Vitu, 2007, for discussions on this). Commonly accepted explanations for the characteristics of the PVL rely on the assumption that the optimal viewing position is specified as the target of saccade programs and that this position corresponds to the centre of the word (McConkie et al., 1989).

The strategic process of selecting saccade targets is intricately dependent on possessing information regarding both the commencement and conclusion points of the designated word. Spaces meticulously interspersed between words in alphabetic scripts fulfil this crucial role. The omission of such inter-word spaces from English texts, for instance, markedly diminishes reading efficiency (Rayner et al., 1998). In these conditions, the Preferred Viewing Location (PVL) curve moves away from its usual Gaussian distribution, assuming a unique shape marked by a significant and linear decrease from the word's beginning to its end (Rayner & Pollatsek, 1996), countering Epelboim et al. (1994) who questioned the PVL phenomenon. Similarly, Kajii et al. (2001) and Sainio et al. (2007) reported in detailing the reading of Japanese, a script characterised by the amalgamation of ideographic characters (Kanji) and syllabic characters (Hiragana, Katakana), and notably devoid of inter-word spaces, researchers have reported the manifestation of linear Preferred Viewing Location (PVL) curves. These findings imply that, in the absence of distinct word boundaries, readers tend to guide their gaze to the beginning of the subsequent word. In fact, when Sainio et al. (2007) introduced spaces within a script solely composed of Hiragana characters, the linear PVL curve, as observed in the "unspaced" text, transitioned to resemble the quadratic PVL curve characteristic of alphabetic scripts featuring inter-word spaces.

Yan, Kliegl, Richter, et al. (2010) proposed a parafoveal word segmentation hypothesis based on these differing PVL curves. They hypothesised that readers would direct their eyes to the word's beginning if they failed to segment the word peripherally but would target the word's centre if they successfully segmented the word with peripheral vision. However, this hypothesis was challenged by Li et al. (2011), who simulated Chinese readers' eye movement behaviour using a constant distance hypothesis. Their simulations produced PVL curves similar to those reported by Yan, Kliegl, Richter, et al. (2010), suggesting that the parafoveal word segmentation hypothesis was not conclusively supported by the observed PVL phenomenon in multiple- and single-fixation cases.

Our study and the results make a unique contribution with respect of language reading order and L2 reading proficiency. At the word-level, we observed significant effects of both word length and word frequency on the variability of initial landing positions. The observation is an important finding in the context of reading Chinese for several reasons. Unlike alphabetic scripts, Chinese is composed of logograms, where each character represents a morpheme and can be a word on its own or part of a multi-character word. The variability in word length and frequency can pose unique challenges in visual processing, making these findings particularly significant for understanding reading strategies in Chinese. These results can inform us about orthographic processing in Chinese reading. Since Chinese characters have no spacing between them, the identification of word boundaries is a critical part of reading. The findings suggest that readers use word length and frequency as cues for where to fixate, which aids in this boundary identification. It is noteworthy that the effect of word frequency was found to be significant only in the Advanced group and not in the Upper Intermediate group of L2 English readers. This suggests that higher proficiency and exposure may lead to more native-like reading, overall.

This illuminates the sophisticated interplay between language mastery and eye-movement behaviour and sets an optimistic stage for future explorations into the cognitive dynamics of bilingual reading.

12.5.3 Interim Summary

Our findings align with previous literature on eye movements in reading, which emphasises the role of word length in guiding visual attention (Reichle et al., 1998b). It further suggests that bilingual readers, regardless of their language background, exhibit similar patterns of word length effects during L2 reading.

Most strikingly, there seems to be a negative effect of L2 reading proficiency on L1 reading – i.e., English on Chinese effect, as observed in decrease in accuracy to landing at the optimal position (compare Advanced vs. Upper Intermediate group of Chinese readers). This finding aligns with the concept of proficiency-dependent transfer effects, which suggests that higher levels of L2 proficiency may introduce increased variability in L1 reading processes (Bialystok, 2007). The results also echo previous research highlighting the role of cross-linguistic interference and transfer in bilingual reading (Bosma & Pablos, 2020). This finding underscores the need to consider the effects of L2 reading proficiency when examining L1 reading processes in bilinguals, as proficiency levels can shape eye-movement patterns.

The third key finding, specific to the Chinese study, reveals the influence of neighbouring word frequency on initial landing positions, particularly within the Advanced group. This finding adds to the growing body of research exploring the impact of word frequency on eye movements during reading (Hyönä & Bertram, 2004; Inhoff & Rayner, 1986). Additionally, our results are in line with the idea that experience in a second language (L2) can modify reading strategies and mechanisms of attention (Sun et al., 2021).

In summarising, this study significantly advances our understanding of how second language proficiency interplays with native language reading mechanisms. We have highlighted the crucial influence of factors like word length and frequency on bilingual readers' eye movements. Our research not only sheds light on the complex cognitive underpinnings of bilingual reading but also opens avenues for practical applications in language education and processing. The path forward is promising, with ample opportunities for further exploration into other dimensions such as reading strategies, language dominance, and individual differences, enriching our grasp of bilingual reading dynamics.

Chapter 13: General Discussion and Conclusion

The focus of this dissertation is on charting changes in eye movement behaviour during reading in Chinese learners of English in the light of L2 proficiency and exposure. Recall that we measure L2 exposure based on participants' durations of staying in the UK, i.e., the number of months they stayed/studied in the UK at the time when they participated in this study (for details see Chapter 3, Section 3.3).

The reading of alphabetic languages like English has undergone thorough investigation, and the majority of eye movement models during reading are grounded in these studies (Pollatsek et al., 2006; Rayner, 2009b; Rayner et al., 2004; Rayner et al., 2006; Reichle et al., 1998a; Reichle et al., 2003; Reichle et al., 2009; Schad & Engbert, 2012; Schotter et al., 2014). However, the findings derived from research on alphabetic scripts may not apply to other writing systems as these systems differ in their visual appearance and the methods by which symbols represent sounds and meanings.

Different writing systems have unique methods of transcribing spoken language into written form. Alphabetic systems, such as English, use letters to denote individual sounds, whereas syllabic scripts like Korean represent entire syllables with each character. On the other hand, logographic scripts like Chinese are not phonetically based. In these systems, which also encompass Japanese kanji and Korean hanja, the characters primarily convey meaning rather than sound.

In logographic writing systems, each character usually represents a basic unit of meaning, akin to a morpheme in Indo-European languages. These morphemes serve as the building blocks of the script. While logographic scripts represent syllables, the pronunciation of a character cannot be determined by assembling or combining parts of the character, as is the case in alphabetic writing systems. As a result, readers of logographic scripts must memorise the pronunciation of each individual character, making it a unique challenge.

In other words, different writing systems have distinct ways of representing sounds through visual symbols, their appearance, layout, and morphological characteristics. To effectively comprehend and engage with text in a specific writing system, readers must consider and adapt to the unique features and conventions of that system.

Furthermore, the perceptual span which represents the visual range of attention during reading, differs across scripts. The differences in the width of perceptual range across different writing systems may be attributed to variations in the visual intricacy of letters or characters. In English the perceptual span can encompass approximately 18-20 letters in total. But the perceptual span is slightly narrower, around 18 letters in total, for Uyghur, which utilises Arabic letters. The span is even narrower, approximately 11-12 letters in total, for Tibetan, an alphabetic script with visually more complex letters compared to English. Similarly, when reading Chinese characters, the perceptual span is rather narrow, about 5 characters in total, thereby supporting the idea that the complexity of the script affects the width of the perceptual span. Collectively, these discoveries (Leung et al., 2014; Risse, 2014; Yan et al., 2015) indicate that readers adjust their attentional focus to adapt to the specific characteristics of the writing system of the language they are reading. However, this span is not distributed equally to the left and the right of the target word: the perceptual span exhibits asymmetry in favour of the reading direction. This suggests that visual attention is preferentially allocated to the upcoming text.

Different models of eye movements in reading propose various assumptions regarding the deployment of attention. One viewpoint suggests that attention is sequentially directed to one word at a time, shifting to the next word after the current one has been identified. In the context of scripts read from left to right, the E-Z Reader model posits that attention usually moves to the word located to the right of where the eyes are fixed before eye movements take place. Therefore, this leads to a broader perceptual span towards the right side in comparison to the left. In contrast, alternative models like SWIFT suggest that attention can be spread across multiple words simultaneously. Yet, due to the greater allocation of attention to the right side of fixation in left-to-right scripts, SWIFT also recognises that the perceptual span is expanded more extensively on the right side relative to the left. In other words, the E-Z Reader model says we tend to focus on the word to the right of where our eyes are before moving them, resulting in better visibility of words on the right. SWIFT, on the other hand, argues that we can pay attention to multiple words at once, with a stronger focus on the right, which means we can see more words to the right clearly. Currently, there is evidence supporting both models, and the precise mechanism of attention deployment during reading is still a topic of debate.

In addition, in most alphabetic writing systems, readers are familiar with text that contains spaces between words. These inter-word spaces serve the purpose of grouping letters into meaningful words (word segmentation), and they aid in the planning of eye movements during reading. The perception of inter-word spaces relies on low-level visual cues, using peripheral vision outside the central high-resolution foveal region to group letters into coherent words. When spaces are removed from text that is typically spaced, it significantly hampers reading comprehension and word identification. Languages that lack inter-word spaces to separate words employ distinct strategies to group consecutive characters into words and facilitate eye movements between them. Consequently, studies conducted on alphabetic scripts do not provide insights into the visual processing of words in unspaced scripts. Moreover, since Chinese text consists of continuous characters without any explicit word boundary information, some character strings can be segmented in multiple ways which makes word segmentation and word identification in Chinese reading worth of further investigation and exploration.

The E-Z Reader model, for example, operates on the assumption that only one word can be processed at a time. While this model has been successful in simulating certain findings in alphabetic writing systems, it encounters challenges when applied to Chinese reading due to the unique characteristics of the Chinese writing system. The E-Z Reader model, including its Chinese version, assumes word segmentation similar to alphabetic writing systems, disregarding the absence of inter-word spaces in Chinese text and the various ways in which words can be segmented. This limitation of the E-Z Reader model in accounting for word segmentation in Chinese reading poses a significant challenge. Chinese readers rely on contextual cues, syntactic and semantic knowledge, and visual features of individual characters to infer word boundaries and segment the text. These strategies involve complex cognitive processes beyond the scope of the E-Z Reader model's assumptions. To overcome this limitation, alternative models have been proposed that incorporate specific mechanisms for word segmentation in Chinese reading. These models consider the contextual and linguistic factors unique to the Chinese writing system, such as character frequency, collocation patterns, and semantic constraints, to guide the process of word segmentation during reading. In summary, while the E-Z Reader model has been successful in simulating certain findings in alphabetic writing systems, its assumptions regarding word processing and segmentation pose challenges when applied to Chinese reading. Recognising the distinct nature of the Chinese writing system and the need for accurate word segmentation models is crucial for advancing our understanding of reading processes in Chinese readers.

The distinctions between Chinese script and alphabetic languages mentioned above served as one of the main motivations for conducting a cross-language eye-movement study that specifically focuses on Chinese and English reading. This study aimed to explore, first, the differences in eye-movements that guide reading between these two typologically distinct languages. The differences in scripts between the two languages have implications for word recognition, visual processing, and the coordination of eye movements during reading.

By examining eye movements of L1 Chinese readers of L2 English and comparing them to how L1 readers read English, we investigated how these distinct linguistic and orthographic characteristics influence eye movement behaviours. More specifically, this study aimed to uncover disparities in eye-movement patterns, in particular in fixation durations and landing positions, and the utilisation of preview information, between Chinese and English readers. Understanding the different eye-movement mechanisms employed in L1 Chinese, L1 English and L2 English reading can provide insights into the underlying cognitive processes and strategies used by readers in each language. It can shed light on the interplay between language-specific factors, such as word segmentation in Chinese and phonological decoding in English, and eye movement control. Moreover, this research has implications for the development of reading theories and models that can accommodate the unique features of different writing systems. By identifying the divergent eye-movement patterns and mechanisms across languages, researchers can contribute to a more comprehensive understanding of reading processes and advance our knowledge of how readers adapt to the specific characteristics of different scripts.

The second part of this dissertation zoomed in on the differences in eye-movement patterns between two groups of Chinese learners of English with varying levels of L2 proficiency, vocabulary sizes in L2, and durations of stay in the UK. The objective was to examine whether any observations regarding their English reading behaviour could be attributed to how these groups read their L1, and whether and how reading habits from their L1 transferred across. This research question arises from the interest in understanding the interplay between L1 and L2 reading eye-movement patterns within the context of Chinese and English, two typologically distinct languages with diametrically opposed writing systems. Understanding the interplay between L1 and L2 reading eye-movement patterns is crucial for gaining insights into how readers adapt their reading strategies across different languages and writing systems. It can provide valuable information on transfer effects, cognitive processing, and the role of language proficiency in reading behaviours. Moreover, investigating the differences in eye-movement patterns between the two groups of Chinese learners of English reading their L1 can contribute to our understanding of how L2 reading experiences might influence L1 reading processes. It offers insights into the potential bidirectional influence between L1 and L2 reading and sheds light on the complex dynamics of bilingual reading.

13.1 Part 1: L2 Proficiency and Exposure Modulate L2 Reading Behaviour

13.1.1 The Effects of L2 Reading Proficiency and Exposure

The first research question investigated how the eye movement patterns, as indicated by the three main fixation measures, of Chinese students who learn and use English as a second language differ based on their different levels of L2 reading proficiency and exposure, and whether a higher level of L2 reading proficiency and exposure is associated with a more native-like reading behaviour, when compared to the eye movements of English native speakers. As there is much less research on the effects of language proficiency and exposure on eye movement in L2 reading compared to research on eye movement patterns provided by skilled native English readers, the first research question can shed light on this topic by providing abundant empirical evidence from eye-tracking data.

Recall that it is generally thought that readers' eye movements reflect their linguistic processing. As one of the most often used early measurements, first fixation duration is viewed primarily as a reflection of highly automated word recognition and lexical access processes. During fixation, readers are thought to employ visual, orthographic, phonological, and morphological information to identify and activate the word's lexical representation which contains information about its meaning. A short duration of the first fixation may indicate that an individual does better in the previously stated operations. For instance, they are more familiar with a certain English word, and it took them less time to recall the word's meaning. Or they acquired this word earlier, i.e., when they acquired this word with earlier used words being entrenched better due to longer exposure. Or, to their exposure to this term, which refers to the number of times they encounter a word throughout their life.

When it comes to L2 reading, there are two hypotheses. First, word recognition and word meaning recall are related to exposure to the L2, their frequency of reading in the L2, the size of their L2 vocabulary, and their speed of converting orthographic information to word meanings. Second, Chinese readers may be relying on 'translation', a process where they mentally convert L2 words into their first language (L1) to understand their meaning. This method involves an additional cognitive step of converting the written text from the second language back into their native language, which can slow down reading speed by increasing the time spent on first fixation durations. These hypotheses can be examined further in two ways, either by relying on properties of their L2 reading, or of their L1 reading, i.e., whether their L1 word recognition speed can be transferred to their L2 word recognition to aid in the reading process.

In the data description sections from Chapter 4 to Chapter 6, we compared and visualised the first fixation durations, gaze durations, and total reading time of both Chinese groups with the native group while controlling for reading order (English first or Chinese first). Across the three variables, whether it is first fixation durations or gaze durations, which are early measures indicative of automatic word recognition and lexical access, or total reading time, a later measure often associated with more deliberate, controlled, and strategic processes, the pattern remains consistent (Staub & Rayner, 2007). According to the results in this study, the durations of the native group who read English as L1 were the lowest. As skilled readers of English as L1, participants of the native group were thus faster at lexical retrieval. However, as L2 readers of English, both Chinese groups had longer first fixation durations and gaze durations, indicating longer lexical-level processing. The result of the current study echoes the existing literature regarding the ‘weaker link’ hypothesis (Gollan et al., 2008) which suggests that bilinguals, compared to monolinguals, have less robust connections between word forms and their lexical representations, owing to limited exposure to their second language. The split frequency of language usage results in a less efficient lexical organisation in both L2 and L1, culminating in extended times for lexical access.

Specifically, our results indicate that readers with lower reading proficiency in their L2 exhibit slower word recognition and access to word meanings, as evidenced by longer first fixation durations and gaze durations. These readers require more time to process individual words, suggesting a greater cognitive effort in decoding and comprehension. Furthermore, readers with lower L2 proficiency also demonstrate prolonged total reading time, indicating a need for additional processing of the overall context, syntax, and discourse of the text. This suggests that lower proficiency readers struggle to efficiently integrate and interpret information at higher linguistic levels, leading to a slower reading pace.

In contrast, readers with higher L2 proficiency and greater exposure to the second language exhibit quicker word recognition and lexical access. Their increased exposure to L2 vocabulary and language structures enables them to make faster connections between word forms and their meanings. As a result, these readers demonstrate shorter total reading time, reflecting a more streamlined and effortless reading process.

Our observed disparities in eye movement patterns, notably in lexical processing efficiency across groups, can be understood through the prism of cross-linguistic influence coupled with sophisticated bilingual lexical access models such as the Bilingual Interactive Activation Plus (BIA++) model. Kroll and Stewart's exploration of cross-linguistic influence (1994) underscores the interactive essence of bilingual lexical access, illustrating how proficiency in a first language influences the processing of a second language. This interaction becomes particularly pronounced in contexts marked by diverse levels of L2 proficiency and exposure, aligning with our study's findings. Moreover, the BIA++ model, comprehensively expounded by Dijkstra and Van Heuven (2002), offers a robust framework for deciphering these linguistic interactions. It proposes that bilingual lexical access is inherently non-selective, with language-specific representations being activated concurrently. This framework compellingly elucidates the varying degrees of lexical processing efficiency noted among our participants. It considers the dynamic reciprocal action between L1 and L2 lexicons, influenced by proficiency and exposure. This model's relevance is bolstered by empirical studies (Blumenfeld & Marian, 2013; Libben & Titone, 2009; Whitford & Titone, 2012b), which affirm its effectiveness in explaining bilinguals' navigational strategies within their linguistic ecosystems. Consequently, our study enriches the body of evidence supporting the BIA++ model's viability, highlighting cross-linguistic influence's pivotal role in melding the reading behaviours of Chinese learners of English across varying L2 proficiency and exposure levels.

What is more, our reported results are in line with those of previous studies related to models of eye movement control. The E-Z reader model delineates word identification through three distinct stages: a pre-attentive early visual processing stage (V), and a later lexical processing stage divided into two attention-demanding substages, culminating in making the word's meaning accessible for further linguistic analysis. Additionally, the model identifies two critical 'signalling' events within these later stages: the end of the familiarity check cues the oculomotor system to prepare a saccade to the next word, and completing lexical access signals the shift of attention to the upcoming word (Reichle et al., 1998b). We found that L2 readers with lower reading proficiency needed more time in the early visual processing stage and later lexical processing stage as they spent more time on familiarity checks and the completion of lexical access compared with the more advanced L2 group.

In conclusion, our study reveals that readers with lower L2 proficiency exhibit slower word recognition and greater effort in accessing word meanings, as well as longer total reading time. In contrast, readers with higher L2 proficiency demonstrate faster word recognition and reduced processing effort. These findings underscore the critical role of L2 exposure and proficiency in shaping eye-movement patterns and overall reading fluency in the second language. As readers become more proficient in their L2 and gain increased exposure to the language, they develop a stronger foundation for word recognition. This, in turn, leads to shorter fixation durations and reduced cognitive load during reading.

These findings have implications for language instruction and the design of reading interventions. They emphasise the significance of providing extensive exposure to the target language and fostering L2 proficiency to enhance reading fluency. Additionally, the findings underscore the need to support readers with lower L2 proficiency through targeted instruction and interventions that address their specific challenges in word recognition and contextual processing.

13.1.2 Foveal Processing

In the preceding section, we focused on the role of reading proficiency and exposure in shaping readers' fixation durations when reading English as a second language (L2). Now, we delve deeper into another crucial aspect: the impact of word length and frequency on L2 reading and eye movements.

Word length refers to the number of letters or characters in a word, and it has been established that longer words tend to elicit longer fixation durations. This is because longer words require additional processing time for visual recognition, phonological decoding, and semantic integration. Consequently, readers often spend more time fixating on these words to extract their meaning effectively.

Word frequency, on the other hand, refers to the relative occurrence or familiarity of a word in a language. High-frequency words, which are commonly encountered in written texts, are processed more quickly and efficiently than low-frequency words. As a result, readers spend less time fixating on high-frequency words, as they can be recognised and understood more easily due to their familiarity.

Understanding how word length and frequency influence fixation durations provides valuable insights into the cognitive mechanisms involved in reading. By investigating these word-level properties, we gain a better understanding of the underlying processes and develop more comprehensive models of eye movement control during reading. Such knowledge has practical implications for educational interventions aimed at improving reading skills in both native and second language learners.

The interplay between word length and frequency has been the subject of extensive research. Studies have shown that longer words with low frequency tend to have the most significant impact on fixation durations, as they present greater processing challenges. Conversely, shorter words with high frequency are typically processed more rapidly, leading to shorter fixation durations.

Prior studies on eye movement control in reading have noted the importance of word level properties (i.e., length and frequency) on fixation durations. In this section, a systematic explanation will cover the main findings from the current study regarding how word length and frequency affect the currently fixated word, the preceding word, and the next word in L2 reading to both Chinese groups with different L2 reading proficiency and exposure.

Word length on foveal processing as measured by fixation durations. L2 readers who are more proficient with more exposure spent less time on word-level reading processing, including automatic word recognition and lexical access (first fixation durations and gaze durations) and later stages of contextual processing. The first fixation durations of the more proficient L2 readers in reading English showed a non-linear relationship with the length of the currently fixated word: when words are shorter than 9 letters, the longer the words, the longer the first fixation durations; yet when the words exceed 9 letters, the longer the words, the shorter their first fixation durations. However, for the less proficient readers the relations are generally consistent, i.e., the longer the words are, the longer the first fixation durations get. This finding reveals a change of word length effect on L2 learners' initial lexical access influenced by the exposure and proficiency. The results have been described in previous research on the different word length effect on adults and children in L1 reading. Firstly, owing to their limited reading experience, children might need a longer or more thorough visual examination of a word to begin and finish lexical processing. This is particularly true for longer words, where more of the word is distant from the point of fixation and thus visually less clear (Aghababian & Nazir, 2000). Secondly, children have a less developed oculomotor system than adults (Klein & Foerster, 2001) and they may not have as fully developed oculomotor mechanisms for efficient reading as have been proposed for skilled readers (Reichle et al., 2003). The oculomotor systems of L2 adults are programmed for their L1 reading and they need to reprogram it when they read in

L2. What is more, adults might need only limited information about a word's identity to program a saccade away from it, whereas children could require more extensive visual data about the word (thus necessitating longer and more detailed visual inspection) before deciding to move on. This becomes particularly vital for effectively processing long words, where a greater portion of the word lies outside the foveal vision. Our results indicate that the more advanced L2 group with more exposure spent less time on lexical access as they only need partial information about a word.

The non-linear and dynamical relationship that was found between the length and the first fixation durations of the currently fixated word on this word thus shed new light on computational models of eye movement, especially when it comes to predicting the mechanism of the eye movements of L2 readers.

Word frequency on foveal processing as measured by fixation durations. As expected, we also found a salient effect of the frequency of the currently fixated word on the fixations on it, both for Chinese readers as L2 readers and English readers as L1 readers.

Regarding the relationships between the frequency of the currently fixated word and the first fixation duration on it, both Chinese groups as L2 readers of English displayed a non-linear relationship with a stronger negative relationship when (log) frequency exceeds 6. Also, the effect of the currently fixated word was found to be stronger on the first fixation durations for the Chinese group than for the English group. The weaker links hypothesis forecasts outcomes akin to those predicted by implicit learning models: more pronounced bilingual versus monolingual frequency effects, due to bilinguals' exposure to more than one language rather than a singular linguistic environment. Put differently, larger bilingual versus monolingual frequency effects suggests that the difference in word processing speed based on frequency is more pronounced in bilinguals. Because bilinguals split their linguistic exposure between two languages, even the frequent words in one language might not be as deeply ingrained or as quickly processed as the frequent words for a monolingual speaker of that language. This leads to a potentially greater discrepancy in processing speed between high and low-frequency words for bilinguals. Moreover, Whitford and Titone (2012b) discovered that the extent of frequency effects in a second language (L2) was inversely proportional to the current levels of exposure to L2. This means that reduced exposure to L2 resulted in more significant frequency effects in L2. The results in this study seem to be consistent with their study as the two L2 groups had larger frequency effects than the native group who read English as L1.

13.1.3 Parafoveal Processing

In addition to examining foveal processing and the impact of word length and frequency on fixation durations on the currently fixated word, our study also investigated the role of parafoveal processing and how it differs between L1 and L2 readers with varying levels of proficiency and exposure.

Parafoveal processing refers to the ability to extract information from the words in parafoveal vision, which is the area surrounding the fixation point. Peripheral vision plays a crucial role in guiding eye movements and facilitating efficient reading. It allows readers to preview upcoming words and process them in advance, enabling smoother and faster reading.

Our study explored how parafoveal processing differs between L1 and L2 readers, particularly focusing on readers with different proficiency levels and exposure to the second language. We aimed to understand whether L2 readers, especially those with higher proficiency and greater exposure, exhibit enhanced parafoveal processing abilities compared to lower proficiency L2 readers, and more similar to L1 readers. By analysing eye movement data and examining fixation durations, we can gain insights into the extent to which L2 readers utilise parafoveal processing to optimise their reading efficiency by extracting information from the parafoveal region and make more accurate predictions about upcoming words.

We found a strong effect of the length and frequency of the preceding word on the fixation durations on the target word. Our result is in line with previous findings reported by Kliegl et al. (2006). A possible explanation for the effect of the length of the preceding word on the fixation durations on the target word is the limit of visual acuity. When the preceding word (word N-1) has a greater number of letters, the fixation tends to occur farther from word N. This distance can lead to a decreased preview benefit for word N, stemming from the decline in visual acuity and the resulting lateral inhibition. As a result, the length of word N-1 is a predictor of the fixation duration on word N. Compared with the strong and salient effect of the length of the previous word on the first fixation durations on the currently fixated word found in the native readers of English, the effect of the length of the previous was found to be weaker and even to show the opposite tendency in both Chinese groups in reading English. One possible reason for this is that in Chinese, about 60–70% of the words are two-character words which weakens the effect of the length of the preceding word on the durations on the currently fixated word due to limits of visual acuity in reading English. In other words, due to their L1, Chinese readers of L2 English do not respond to word length as L1 readers do, not even the more advanced L2 readers.

In short, we found that, as L2 readers of English, Chinese participants in both groups showed weaker effects of the length of the previous word on the first fixation durations on the currently fixated word. From the perspective of literature on second language acquisition, it is reasonable to assume that L2 readers have a narrower perceptual span than L1 readers (Leung et al., 2014). The rationale behind this assumption is as follows. The first one is limited language proficiency. L2 readers are typically less proficient in the second language compared to their native language. As a result, their ability to rapidly process and comprehend text in the L2 may be compromised. This limitation in language proficiency can impact their reading speed and efficiency. Increased cognitive load is the second assumption. Reading in a second language often requires more cognitive effort because L2 readers need to translate words or phrases and decode unfamiliar linguistic structures. This additional cognitive load can lead to a narrower perceptual span as L2 readers may need to allocate more attention and processing resources to individual words or smaller chunks of text. The third one is the word recognition challenges. L2 readers may encounter difficulties in recognising words and word patterns in the second language, especially if the L2 script is different from their L1.

Understanding the differences in parafoveal processing between L1 and L2 readers with varying proficiency levels and exposure has important implications for reading instruction and language learning. It can inform the development of effective reading strategies and interventions that specifically target the enhancement of parafoveal processing skills. Moreover, studying parafoveal processing in L2 reading sheds light on the interaction between L1 and L2 reading mechanisms. It allows us to examine how readers with prior reading experience in their L1 adapt and transfer their reading strategies and skills to the L2 context.

In summary, our study goes beyond foveal processing and investigated the role of parafoveal processing in L2 reading. By comparing L1 and L2 readers with different proficiency levels and exposure, we aimed to uncover potential differences in their ability to utilise parafoveal information during reading. These findings contribute to our understanding of how readers optimise their reading processes and adapt their strategies in different language contexts, thereby informing effective reading instruction and language learning practices.

13.1.4 Landing Position in L2 reading

Saccadic eye movements play a crucial role in continuously gathering visual information while reading text. The specific location where a saccade lands on a word determines the sensory input to the reader's central and peripheral vision. This so-called landing position significantly influences the cognitive effort and reading speed, connecting the spatial ("where") and temporal ("when") aspects of eye movements. Various studies (e.g., S. Liversedge & Findlay, 2000 ; Radach & Heller , 2000; Rayner, 1998) have highlighted the important relationship between eye movement patterns and reading processes. Consequently, theoretical, and computational models of eye movement control during reading focus on determining which position within a word is targeted by a saccade and explaining any discrepancies between the intended and actual target (Rayner, 2009a).

During English reading, it is generally presumed that the initial saccade on a word aims for the word's centre, regarded as the optimal view position (optimal landing position). Yet, in practice, the eyes often fall short of this optimal position, landing instead at the preferred viewing position (PVL, Rayner, 1979), which is halfway between the beginning and the middle of a word (McConkie et al., 1988). In English reading, the guidance of eye movements benefits from the spaces between words, as these spaces assist in defining the boundaries of words before the eyes actually fixate on them (Reichle et al., 1998b). Earlier eye-tracking research, which uncovered fundamental aspects of oculomotor control in reading alphabetic languages, indicates that the distribution of saccadic landing positions on a word, assuming a constant launch site and word length, seems to follow a normal distribution (McConkie et al., 1988). While the mean of this distribution can be interpreted as the overall efficiency of saccadic targeting since landing at the middle point indicates efficient saccade planning, its dispersion (i.e., standard deviation) can be linked to targeting accuracy. However, the tendency for saccades to have a systematic bias towards a preferred length can lead to the actual saccade adjusting its length and resulting in a landing position that deviates from the intended target, either falling short (undershoot) or going beyond it (overshoot).

We found a clear difference between the two Chinese groups and the native English group with regard to the dispersion of the relative landing position. Our results from English readers confirmed that the landing positions of skilled readers are closer to the middle of the word with very little variation. Compared with the native group, as the length of the currently fixated word N gets longer, the landing positions of the two Chinese groups tend to move further away from the centre of the word. More specifically, the initial landing position of the L2 groups fell further to the left of the centre of the word as the length of the currently fixated word increases. Chinese readers do not have much experience with longer words as Chinese words vary little in length. Therefore, Chinese participants do not demonstrate the same level of precision and smoothness in adjusting their eye movements for saccades, starting to undershoot from 5-letter words, a pattern even observed in advanced L2 readers.

Transitioning to the implications of these findings, we observe that longer fixations on word N provide an extended preview of the subsequent word (word N+1). This extended preview period facilitates more accurate saccadic planning and targeting towards the centre of word N+1. This phenomenon, known as the preview effect, along with the utilisation of preview benefits for saccadic targeting, requires considerable practice and experience, as noted by McConkie et al. (1988).

Building on these insights, our modelling results further illuminate the dynamics at play. When examining the effects of word-level properties on relative landing positions, we observed a compelling pattern among both Chinese groups compared to the native group. Specifically, the length of the currently fixated word (word N) had a statistically significant impact on the relative landing positions of the Chinese readers in both reading orders. Intriguingly, this effect was not mirrored in the native English group. This divergence underscores the nuanced differences in reading strategies and eye movement patterns between native and non-native readers, especially in response to word length variations.

These findings suggest that skilled L1 English readers, represented by the native group, do not exhibit a strong influence of word length on their saccadic programming: the length of the currently fixated word does not significantly impact where their gaze lands within the word during reading. Proficient L1 readers have developed efficient saccadic programming strategies that are resilient in the light of word length. On the other hand, the Chinese L2 readers demonstrated a different pattern. Their saccadic programming appears to be influenced by the length of the currently fixated word, as evidenced by the statistically significant relationship between word length and relative landing positions. This suggests that for L2 readers, the length of the word being fixated still plays a role in guiding their eye movements.

These findings highlight the potential differences in saccadic programming strategies between skilled L1 readers and L2 readers. Skilled L1 readers seem to have more stable and efficient saccadic programming that is less influenced by word length, whereas L2 readers may still rely on word length as a cue for guiding their eye movements. Understanding these differences in saccadic programming between L1 and L2 readers contributes to our knowledge of how reading skills develop and adapt in different language contexts. It emphasises the importance of considering both language proficiency and reading experience when examining the influence of word-level properties on eye movements.

L2 readers often struggle to attain native-like proficiency, mainly due to limited exposure and experience. This scenario can result in greater oculomotor variability, affecting the precision of saccadic targeting and leading to a wider spread in the distribution of landing positions. The aforementioned influencing factors, combined with random oculomotor errors, form the basis of the architectural principles used in computational models of eye-movement control in reading (Reichle et al., 1998a). The debate continues about whether saccadic targeting in reading is solely influenced by the visual attributes of text or if cognitive factors also play a role. Earlier research suggests that readers' eye movements are directed by visual indicators like word length and spaces (McConkie et al., 1988; Radach et al., 2007; Reichle et al., 1998a). Our data suggests that the dispersion of the two Chinese groups as L2 readers is much greater than that of the native group, which means that compared with the native group, L2 readers showed less accuracy in saccadic targeting. There is a need for longer experience or more exposure to achieve accuracy of motor control.

13.1.5 Reading L1 with Similar Content Facilitates Lexical Processing in L2 Reading

This study included two reading tasks, i.e., the Chinese reading task and the English reading task. We prepared stimuli for the Chinese reading tasks with topics similar to the English ones by searching for the same keywords online. We treated the similarity between stimuli in both languages as a control variable in the data analysis as it might affect the results. However, we found a statistically significant influence of reading order (reading Chinese first or reading English first) on the reading behaviours of our L2 participants. More importantly, the effect of reading order factually exerted different influences on the two Chinese groups with different L2 proficiency. Both Chinese groups benefitted from reading Chinese texts with similar content and topics first in that it significantly facilitated lexical processing, as indicated by shorter first fixation durations, gaze durations, and total reading time. Another intriguing finding based on the analyses of fixations related to the impact of reading Chinese as a first language (L1) on the eye movements of second language (L2) reading is the effect of allowing less skilled L2 readers to first read the texts in their native language. Surprisingly, this practice has been shown to enhance their performance to the extent that it becomes indistinguishable from the more advanced group who received more exposure to the L2. These are valuable results in that they can inform L2 reading teaching in general and fit with schemata theory, which is often applied to reading in a foreign language.

Typically, readers derive meaning from hints within a text, a process linked to employing their background knowledge to comprehend the passage's content. Reading is an interactive activity where readers build a meaningful interpretation of the text through the use of their schemata. Schemata theory (Xie, 2017) outlines how readers integrate their personal background knowledge with the information presented in a text to understand it. Each reader possesses unique schemata (background information). This concept plays a crucial role in teaching English as a Foreign Language (EFL), where reading tasks are often structured to stimulate the learners' relevant schemata.

A schema represents the knowledge previously acquired from experiences and retained in the mind. It constitutes an abstract framework of understanding (Li et al., 2007). Typically, schemata are categorised into three main types: linguistic, formal, and content schemata, all of which play significant roles in reading comprehension. Linguistic schemata encompass a reader's existing language skills, including vocabulary, grammar, and idioms. Formal schemata involve the organisational patterns and rhetorical structures found in written texts. Content schemata, on the other hand, pertain to the reader's background knowledge about the subject matter of a text. This includes familiarity with the topic, cultural understanding, and previous experiences in the relevant field. Content schemata focus on knowledge specific to the text's subject area, crucial for text comprehension. Language is not just a collection of vocabulary and grammatical structures; it also conveys various levels of cultural nuances. To a certain degree, content schemata can compensate for limitations in language schemata, aiding learners in understanding texts through prediction, information selection, and ambiguity resolution. Many studies (Carrell, 1987; Keshavarz et al., 2007; Klein & Foerster, 2001) indicate that readers' content schemata have a more substantial impact on their reading comprehension compared to formal schemata. Generally, familiarity with the topic directly affects word recognition. The more a reader knows about the topic, the easier and faster they can grasp the text's information. Therefore, to become an efficient reader, one should strive to acquire knowledge across a broad range of fields and topics. Learners with more extensive prior knowledge tend to understand and retain more information from the text.

What we found in our data supports schemata theory, more specifically the content schemata and its influence on reading fluency. Gilakjani and Ahmadi (2011) explained the relationship between L2 reading and schema theory related to text familiarity. They highlighted that the impact of a familiar context on a student's reading comprehension reinforces the idea that understanding a text is contingent on the amount of relevant prior knowledge the reader possesses about the text's subject matter. They further suggested that students should be made aware of the components of successful reading. In essence, students should be encouraged to activate their content schemata to reconstruct meaning from the text, rather than concentrating solely on word-by-word decoding. In this study, we focused on ‘word-for-word deciphering’ as we reported fixation durations with each word as an interest area. Our results reveal that the content schemata of participants can be revealed at the word level, i.e., shorter first fixation durations, shorter gaze durations and shorter total reading time in reading English L2. Our results, for the first time, provide evidence for the facilitating effects of reading familiar content in L1 on readers’ L2 reading fluency as captured by eye-tracking measures.

This result highlights the transferability of reading skills from the L1 to the L2 context. By providing less skilled Chinese readers the opportunity to read the texts in their native language initially, they can activate their existing reading abilities and strategies developed through their L1 literacy. As a result, when subsequently reading the same texts in the L2, these readers exhibit eye movement patterns and performance levels that are comparable to those of the more advanced group.

The implications of this finding are significant. It suggests that leveraging knowledge acquired while reading in the L1 can be beneficial for L2 reading. By capitalising on the foundation established in the L1, less skilled L2 readers can achieve similar reading proficiency as their more advanced counterparts. This finding underscores the importance of recognising the interplay between L1 and L2 reading skills and the potential for positive transfer effects. It also highlights the potential benefits of incorporating L1-based strategies and interventions in L2 reading instruction, particularly for individuals who may struggle with L2 reading proficiency. Further research is needed to investigate the underlying mechanisms behind this phenomenon and to explore its applicability in different linguistic and cultural contexts.

13.1.6 Word Order in L2 Reading

Likewise, the word order (word and story order) effect which was included as a control variable was found to be statistically significant to influence the fixation durations in the English reading task. More specifically, the word order effect was significant for the native group who read English as L1 and the Advanced L2 group with L2 when they read English texts first. The native group displayed shorter first fixation durations across trials: as participants in the native group read more texts and words, their first fixation durations decreased. That is, as they came towards the end of a story, and towards the end of the experiment, their first fixation durations shortened. We observed the same effect in the more advanced L2 group when reading English: the more they read, the faster their word recognition and lexical access became. However, for the more advanced group, this native-like word order effect was only found when they read English first, without knowing the topic and content of reading texts in their L1 first. With prior experience of reading similar content in L1, there was no effect of the word order on the word recognition and lexical access time, indicated by first fixation durations, in L2 reading. However, we did not observe the same influence of word order on the first fixation durations of the less advanced L2 readers. This implies that prior knowledge acquired through L1 reading may influence or interfere with the L2 reading process, potentially impacting the efficiency of word recognition for these readers.

13.2 Part 2: L2 Proficiency and Exposure Modulate L1 Reading Behaviour

The second part of this research focused on charting the differences in eye-movement patterns between both groups of Chinese learners of English who had varying levels of language proficiency, vocabulary size, and durations of stay in the UK when they read Chinese as their first language (L1), to establish whether their proficiency in their L2 and their time away from their L1 would affect their L1 reading behaviours. The findings of this study align with previous research on Chinese reading in several aspects, confirming existing knowledge. However, this study also presents novel findings that contribute to eye movement control models, and theories in second language reading research and have potential implications for teaching practices.

13.2.1 The Effects of L2 Reading Proficiency and Exposure

Recall that in this study, Chinese participants were divided into two groups based on their L2 proficiency and exposure (IELTS reading scores, months of staying in the UK and their scores in the English vocabulary test). To investigate whether these two groups differ in their Chinese reading habits already, eye-movement patterns (i.e., fixation durations) in the Chinese reading task were reported and analysed for both

Chinese groups, using the same groupings. We did so with the aim to investigate the relationships between L2 proficiency and exposure and L1 reading fluency.

Different from what we found for reading English as L2, participants with lower L2 proficiency and exposure were faster at lexical processing and required less re-reading when reading Chinese as L1. The differences in the fixation durations between L1 and L2 reading suggest an interesting conclusion, i.e., that higher L2 proficiency and more L2 exposure slowed down the speed of lexical access and subsequent reading processes, such as syntactic integration, in L1 reading (Clifton Jr et al., 2007; Vasishth et al., 2013). In other words, we found that increased exposure to and higher reading proficiency in English positively influenced L2 reading fluency in English but this facilitative effect in English was paid for by a negative impact on their reading fluency in their L1, Chinese.

These results indicated that, as Chinese L2 readers gained more exposure to and developed higher reading proficiency in English, their reading fluency in English improved significantly. Increased practice and proficiency in English reading leads to enhanced fluency in processing and comprehending English texts, indeed. Conversely, this enhancement in English seems to slightly affect their reading fluency in Chinese, their L1. As their focus was increasingly drawn to reading in English, there seemed to be a slight decline in their Chinese reading fluency. This finding implies that increased exposure and higher proficiency in English may have interfered with their automaticity and fluency in reading Chinese, as they dedicated more cognitive resources and more time to English reading, causing attrition of their L1 reading skills. Chinese international students in the UK had spent a more extended period away from China, residing in England for an extended duration. Consequently, they had less exposure to

Chinese written materials, leading to a decline or attrition in their Chinese language skills. This contrasting impact on reading fluency highlights the complex relationship between L1 and L2 reading abilities, at least in L2 cohorts that reside abroad. While exposure and proficiency in L2 can lead to increased reading fluency in the second language, it may come at the expense of reading fluency in the native language.

These findings have implications for language education and bilingual instruction. They suggest the importance of maintaining and nurturing reading skills in both L1 and L2, recognising the potential trade-offs and challenges that can arise when focusing extensively on one language at the expense of the other. It underscores the need to strike a balance between developing proficiency in the second language while preserving and sustaining reading fluency in the native language.

13.3.2 Foveal Processing

Recall that in the English reading study, the frequency and length of the currently fixated word were found statistically significant for both Chinese groups in predicting their first fixation durations, gaze durations and total reading time in reading English as L2. Likewise, the frequency of the currently fixated word was statistically significant for the three eye-movement measures in reading Chinese as L1. However, the length of the currently fixated word was only found significant to modulate the total reading time as a late measure and did not affect the first fixation durations and gaze durations as early measures.

It is important to note that the influence of word length on other eye movement measures, such as first fixation durations or gaze durations, was not observed in this study. This indicates that the effects of word length may be more pronounced in later reading stages, reflecting the intricate interplay between word properties and the overall reading process. In this study, we found indeed that the word length of the currently fixated word had a significant impact on the total reading time, particularly as a late measure related to rereading and contextual factors. This suggests that word length becomes more influential during later stages of the reading process, potentially when readers encounter difficulties or require additional processing. The length of the currently fixated word seems to contribute to the overall reading time, as readers may spend more time on longer words, especially when considering the impact of contextual factors and the need for rereading.

We did find a statistically significant word length effect of the currently fixated word on the three duration-related measures when both groups of Chinese participants were reading English as L2 but not all in their L1 reading. Zang et al. (2018) reported the absence of a word length effect in first and single fixation duration in their study about word length effects in Chinese reading. They suggested that the lack of word length effects on the duration of first and single fixations could be attributed to the absence of spaces in Chinese texts. Additionally, they observed that despite the absence of spaces between words in Chinese, and the relatively shorter and less variable word lengths compared to English, word length still significantly influences eye movement patterns during Chinese reading. More specifically, when they examined the target word (with its stroke number considered as a covariate), they found that longer words required more time for processing. This effect was primarily driven by a higher frequency of refixations rather than changes in the duration of the first or single fixations (Rayner, 2009b). Understanding the specific influence of word length on total reading time provides valuable insights into the dynamics of eye movements and reading comprehension.

13.2.3 Parafoveal Processing

In addition to foveal processing, we also examined parafoveal processing. The effect of the properties of the previous word N-1 on the currently fixated word N reported for Chinese reading in this study confirm what was found in previous Chinese reading research regarding word frequency. Li et al. (2014) found, in reading Chinese, spill-over effects from word N-1 on word N for frequency and inverse spill-over effects for word length: gaze durations on word N decreased when word N-1 was more frequent, or longer. Our results also showed that, as the frequency of the previous word increases, the gaze durations, as well as first fixation durations and total reading time on the currently fixated word decrease. However, the relationships are not linear, and only apply when the frequency of the previous word exceeds 6 letters (after power transformation).

Our study yielded intriguing findings regarding the relationship between the frequency of the previous word and various measures of gaze durations in reading. We found a distinct pattern wherein, as the frequency of the previous word increased, there was a noticeable decrease in gaze durations, including first fixation durations and total reading time, on the currently fixated word. This suggests that the higher frequency of the preceding word has a facilitative effect on the processing of the current word, leading to shorter fixation durations. Upon closer examination, we found that the observed effects were only significant when the frequency of the previous word exceeded a threshold of 6 (after applying a power transformation, the raw frequency is 810 in Chinese lexical database). In other words, the impact of the previous word's frequency on gaze durations was more pronounced when the frequency level was relatively high.

These findings suggest that the frequency of the preceding word can influence the reading process and subsequent fixation durations. When encountering a high-frequency word preceding the currently fixated word, readers exhibited shorter gaze durations, indicating a more efficient processing of the text. However, this effect was not evident with lower frequency preceding words, suggesting a threshold for the facilitative influence of word frequency on gaze durations.

Non-linear relationships between frequency and gaze durations highlight the intricate nature of the reading process and the interplay of multiple factors. Factors such as word predictability, contextual cues, and semantic priming may interact with word frequency to influence gaze durations.

These non-linear relationships emphasise the intricate nature of the reading process, highlighting the importance of considering various factors when examining eye movements during reading. Further research is warranted to explore the underlying mechanisms that contribute to these patterns and to elucidate how they may differ across different reading contexts and populations.

Understanding the non-linear nature of these relationships is essential for developing comprehensive models of eye movement control in reading. It underscores the need to consider the dynamic and context-dependent nature of word processing and the potential interactions between various linguistic and cognitive factors.

13.2.4 Landing Position in L1 Reading

We also examined the landing position when Chinese participants with various L2 proficiency and exposure read Chinese. The variabilities of the initial landing positions of the Advanced group were found to be much larger than those of the Upper

Intermediate group. Greater variability in the initial landing positions indicates less precision and fewer possibilities of reliably fixating on the centre of the currently fixated word. The group of Advanced L2 readers encountered difficulties in consistently programming saccades to the optimal landing position when reading in their L1. In contrast, the less advanced L2 group demonstrated more consistent ability in programming saccades to the desired landing position during L1 reading. Put differently, it is easier for the participants in the Upper Intermediate group, i.e., the less proficient group of L2 with less L2 exposure, to reliably fixate on the centre of the currently fixated word when reading in their L1 than for the Advanced group who have higher L2 proficiency and more exposure in L2. This finding suggests that higher L2 proficiency and exposure may disrupt the precise control of eye movements during reading in the L1. The increased linguistic and cognitive demands associated with higher proficiency levels in an L2 may impact the ability to consistently and accurately program saccades to the most advantageous positions for efficient reading in L1.

These results highlight the complex relationship between L2 proficiency, exposure, and eye movement control in reading. They suggest that while higher L2 proficiency and exposure may confer certain advantages in overall reading abilities, they may also introduce specific challenges in the fine-grained control of eye movements in the L1.

Further research is needed to explore the underlying mechanisms and potential contributing factors to this phenomenon. Investigating the specific cognitive processes involved in saccade programming and the effects of L2 proficiency and exposure can provide valuable insights into the interplay between language proficiency and eye movement control during reading.

In addition, we examined the effects of word length and frequency on the variability of initial landing positions at the word level. We observed that both word length and frequency exerted an influence on the variability of initial landing positions during the reading process. Longer words tended to exhibit greater variability in initial fixation position. This suggests that word length impacts the precision and consistency of initial eye movements, potentially reflecting the additional processing demands associated with longer words. Furthermore, word frequency also played a role in the variability of initial landing positions. Words with lower frequencies showed increased variability in initial fixation locations compared to high-frequency words. This suggests that the familiarity and predictability of high-frequency words may contribute to more consistent and accurate initial eye movements to L2 readers given their different L2 proficiency and exposure.

13.2.5 Reading L2 with Similar Content Facilitates Lexical Processing in L1 Reading

In this study, we observed that initial exposure to Chinese text significantly enhanced lexical processing during second language (L2) reading for both Chinese groups. However, the impact of first reading similar content in L2 on first language (L1) reading differed between the two groups.

For first fixation durations in L1 (Chinese) reading, neither group showed reduction in durations after reading similar texts in their L2. In fact, this exposure resulted in a negative effect, lengthening the first fixation durations for both groups.

In terms of gaze durations, a notable difference emerged between the Upper Intermediate and Advanced groups. The Upper Intermediate group exhibited significantly shorter mean gaze durations in reading Chinese as L1 when reading Chinese texts first. Conversely, their gaze durations increased when they read similar English texts first. This pattern mirrored the findings for first fixation durations, suggesting that prior English reading led to longer gaze durations in Chinese for the Upper Intermediate group.

For the Advanced group, reading English texts initially did not lead to a statistically significant decrease in their average gaze duration. This outcome is consistent with our findings on the first fixation durations within the same group; specifically, there was no significant reduction in the length of their initial fixations when comparing different reading sequences. On the other hand, when it comes to the late measure, total reading time, we discovered that reading L2 texts with similar content first facilitated the reading fluency of Chinese readers with greater L2 proficiency and exposure in reading English. This finding is supported by a statistically reduced total reading time for participants in the Advanced group reading Chinese as L1 in the condition where English is read first as L2.

We have now come to the point where we can interpret this study's findings regarding the similarity and familiarity of the topic and its influence on lexical processing. Firstly, at the early stage of lexical access and word recognition, reading similar content in L2 did not help Chinese readers when reading Chinese as L1; more specifically, it did not make them faster at lexical access and quicker word recognition. However, a facilitative effect of reading similar texts in the L2 first started to emerge at the later stage of post-lexical integration but only for L2 readers with higher proficiency and exposure. This suggests that with higher proficiency and exposure, L2 Chinese readers of English managed to use familiarity with the content obtained through their L2 to help them reduce rereading/refixation (indicated by shorter total reading time) in their L1. On the whole, familiarity with the topic has a direct influence on L2 readers' post-lexical processing. Li et al. (2007) reported that the more the reader knows about the topic, the more easily and quickly they extract information from the text. However, only Chinese learners of English as L2 with high proficiency and exposure accessed the main topic and meaning of the text while reading English as L2 which in return helped them to shorten the total reading time on words with less rereading in their L1. Yet, the facilitative effect of reading L2 texts first was not found at the early stage which is about decoding and lexical recognition in L1 reading.

13.2.6 Word Order in L1 Reading

In terms of the differences between the effects of word order in reading Chinese, our result casts a new light on the possible influence of prior L2 reading on L1 reading patterns. Firstly, the Upper Intermediate group with lower L2 proficiency and exposure behaved more consistently than the Advanced group did in this respect: regardless of whether they had read similar texts in their L2, the Upper Intermediate group exhibited shorter fixation durations when reading Chinese, especially as they reached the later stages of the study. Put differently, the more Chinese words the Upper Intermediate group read, the faster their word recognition was. This finding strongly suggests that increased exposure and practice with Chinese reading materials positively influence the efficiency of accessing and recognising words in reading Chinese as L1.

However, the speed of word recognition when reading Chinese as L1 changed dramatically for the Advanced group if they had prior practice of reading similar content in L2. The situation is complex. If the Advanced group first read Chinese texts without prior exposure to English texts with similar content, the more texts they had read, the faster their word recognition became at the initial stages when reading Chinese as L1. However, as they progressed through the texts and approached the half-way point, their word recognition speed slowed down, as indicated by longer first fixation durations on each word. This deceleration in word recognition speed persisted until the end of the study. This pattern suggests that although initial exposure to more texts improved their word recognition in L1, the continuous reading of similar content led to a decline in efficiency, potentially due to fatigue or saturation of processing resources. In contrast, when participants who were more advanced in L2 (English) first read English texts and then switched to reading Chinese texts, a different pattern emerged. As they read more Chinese texts, their word recognition speed in reading Chinese initially slowed down. However, as they progressed towards the half-way point of the study, the more texts they read, the faster they became at lexical recognition in reading Chinese L1. This accelerated word recognition speed continued until the end of the study. This unexpected finding suggests that prior exposure to English texts as L2 influenced the subsequent reading of Chinese texts for the more advanced L2 group, leading to a unique pattern of word recognition.

The contrasting effects of word order on the first fixation durations of Chinese readers when reading Chinese L1 with higher proficiency and exposure in L2 raise intriguing questions that require further investigation. Understanding the underlying mechanisms and factors that contribute to these differences can provide valuable insights into the complex interactions between L1 and L2 reading processes.

Further research is necessary to explore the specific cognitive processes and individual differences that may account for these observations. Examining factors such as language transfer, cognitive load, and the interplay between L1 and L2 reading strategies can shed light on the underlying mechanisms and contribute to a more comprehensive understanding of bilingual reading.

The findings of our study offer empirical evidence pertaining to the schema theory and its association with second language (L2) reading. Specifically, we observed that less advanced L2 readers with lower language proficiency and more limited exposure did not demonstrate faster first fixation durations as they progressed through reading more words and reached the end of the task. Contrary to the expectation of an increasing word-level processing speed over time, this pattern of accelerated reading was not evident in terms of first fixation durations for the less advanced L2 readers. For the less advanced L2 readers this ever-increasing word-level processing speed was statistically significant only in terms of gaze durations and total reading time. This indicates that, while the first fixation durations did not exhibit a significant change, the overall reading process, as reflected in total reading time, did show a significant acceleration as the readers progressed through the text. These findings align with the principles of the schema theory, which suggests that readers with less linguistic knowledge and familiarity may struggle to develop a robust cognitive framework (schema) for efficient text processing. As a result, their reading speed, as indicated by first fixation durations, may not demonstrate the expected increase. However, the overall reading process, as indicated by gaze durations and total reading time, may still exhibit signs of accelerated processing due to the accumulation of comprehension and integration efforts.

These empirical results contribute to our understanding of L2 reading and highlight the complexity of reading behaviour, particularly among less advanced L2 readers. They underscore the importance of considering multiple measures of reading performance and the role of cognitive schemas in shaping reading processes.

13.3 Conclusion

This study embarked on a comprehensive exploration of the influence of L2 reading proficiency on eye movements, and it meticulously examined the disparities in eye movement behaviours during L2 reading among L2 learners characterised by differing L2 proficiency levels and exposure. The key insights derived from this research in the realm of L2 reading unveiled a significant connection between L2 proficiency and exposure and the variations observed in early-stage lexical processing during reading, particularly evident in measures such as first fixation duration and gaze duration. In contrast, the late-stage processing, associated with contextual and discourse-level comprehension, showed relatively less sensitivity to these factors, as indicated by total reading time. Furthermore, irrespective of the presentation order of stimuli in either L1 or L2, proficiency had a discernible impact on first fixation duration, duration of gaze, and the overall gaze duration during natural L2 reading. Remarkably, L2 reading proficiency and exposure emerged as significant predictors of word fixation duration. Additionally, the eye movement patterns of L2 readers possessing higher proficiency and greater exposure closely resembled those of native English readers, revealing a convergence in their reading behaviours.

Our investigation's insights into the eye movement behaviours of Chinese learners of English, considering their varying levels of L2 proficiency and exposure, furnish pivotal implications for advanced models of bilingual reading, particularly the Bilingual Interactive Activation Plus (BIA++) model. The differential patterns of lexical processing efficiency we observed lend empirical support to the BIA++ model’s concept of non-selective and parallel activation of bilingual lexical systems. This model, effectively encapsulates the dynamic interplay between the L1 and L2 lexicons, influenced by individual differences in language proficiency and exposure. The variations in eye movement metrics across proficiency levels and exposure durations in our study not only corroborate the BIA++ model's foundational principles but also emphasise the model's robustness in explaining the complexity of bilingual lexical access. These findings call for a more nuanced understanding of the BIA++ model, suggesting that future enhancements should account for the variability in bilingual readers' eye movement behaviour as a function of their language proficiency and exposure. Thus, our research contributes to the refinement of bilingual lexical access models, underlining the critical role of empirical eye movement data in elucidating bilingual reading processes.

Expanding on these findings related to L2 readers engaging with English text, we extended our investigation to scrutinise the eye movements and reading behaviours of L2 readers when reading in their L1. An intriguing discovery emerged: even though L2 readers with superior proficiency and heightened exposure in their L2 exhibited greater fluency in lexical decoding and overall reading fluency in the L2, they paradoxically displayed slower reading speeds when engaging with text in their L1. This phenomenon was substantiated by prolonged first fixation duration, gaze duration, and total reading time in L1 reading. This apparent language attrition raises intriguing questions about the potential adverse effects of extensive L2 reading experiences on L1 reading fluency, warranting further exploration in future research endeavours.

As an ancillary finding, initially implemented as a control variable, our study uncovered the impact of allowing less proficient Chinese readers to first read texts in their native language (L1) before transitioning to the L2. Astonishingly, this practice led to a marked improvement in their performance, to the extent that it became indistinguishable from the more advanced group with greater exposure to the L2. This discovery underscores the potential benefits of facilitating L1 reading prior to engaging with an L2, suggesting a valuable pedagogical strategy for enhancing L2 reading fluency among learners of varying proficiency levels.

While our research investigates the intricacies of eye movements, it extended beyond mere fixation patterns, focusing on the 'where' aspect of oculomotor control, particularly in the context of Chinese reading and its implications for L2 reading. This exploration allowed us to unearth intriguing differences between two distinct groups of Chinese readers, as they exhibited significant variations in fixation durations. Notably, their landing positions during reading were quite similar, yet they displayed a more considerable range of landing positions when compared to native English readers. These findings hold crucial implications, shedding light on the influence of language-specific word length distributions on saccade planning during L2 reading. This nuanced understanding contributes to the development of more dynamic eye movement control models, offering valuable insights for refining existing models such as E-Z reader and SWIFT, thereby enhancing our comprehension of the intricate processes governing eye movements during reading.

13.4 Limitations and Future Research

This thesis has made significant strides in understanding the nuances of L2 reading behaviour. However, it is important to acknowledge certain limitations that pave the way for future research. One key aspect is the recognition that other properties of words, such as word predictability, might also play a significant role as predictors in L2 reading. While this research focused on specific variables like word length and frequency, the influence of predictability has been noted but not explored in depth. Future studies should aim to incorporate this dimension to provide a more comprehensive understanding of how various word properties interact and affect L2 reading behaviour.

Additionally, the methodology employed, while robust, has its constraints. The use of advanced statistical models like mixed-effects models provides a solid foundation for analysing reading patterns. Future research could explore alternative modelling approaches or validate these findings across different contexts and populations.

Looking forward, there are exciting avenues for expanding upon the findings of this thesis. Firstly, acknowledging the potential significance of word predictability as a predictor in L2 reading, future research should aim to integrate this variable. This integration could offer a more nuanced understanding of the cognitive processes involved in L2 reading and how learners navigate different textual complexities.

Moreover, this thesis lays a groundwork that can significantly contribute to the field of language testing. With the increasing accessibility of eye-tracking technology, such as webcam-based systems, there is an untapped potential to use eye-tracking data in assessing language development. Particularly, this approach can revolutionise how we understand and evaluate the reading and eye movement development of L2 learners in reading English. Eye-tracking technology provides objective, detailed insights into the reading process, which traditional assessment methods might overlook.

Future studies could design and implement language tests that incorporate eye movement data, offering a more holistic and precise assessment of a learner's reading capabilities. This approach not only promises to enhance the accuracy of language proficiency evaluations but also provides learners with feedback that is deeply rooted in the cognitive aspects of language acquisition. Such advancements could be particularly beneficial in educational settings, providing educators and learners with tools to monitor and support the development of reading skills in a second language.

By exploring these areas, future research based on this thesis can continue to make meaningful contributions to the fields of psycholinguistics, language assessment, and second language acquisition.

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Appendices

Appendix 3A Ethics Approval

Dear Shiyu He,

Re: "Learning to optimize reading: evaluating the transfer of "physical" reading strategies across typologically unrelated languages"

Application for Ethical Review ERN_19-1367

Thank you for your application for ethical review for the above project, which was reviewed by the Humanities and Social Sciences Ethical Review Committee.

On behalf of the Committee, I confirm that this study now has full ethical approval. I would like to remind you that any substantive changes to the nature of the study as described in the Application for Ethical Review, and/or any adverse events occurring during the study should be promptly brought to the Committee's attention by the Principal Investigator and may necessitate further ethical review.

Please also ensure that the relevant requirements within the University's Code of Practice for Research and the information and guidance provided on the University's ethics webpages (available at https://intranet.birmingham.ac.uk/finance/accounting/ResearchSupportGroup/ResearhEthics/Links-and-Resources.aspx) are adhered to and referred to in any future applications for ethical review. It is now a requirement on the revised application form (https://intranet.birmingham.ac.uk/finance/accounting/Research-Support-Group/ResearchEthics/Ethical-Review-Forms.aspx) to confirm that this guidance has been consulted and is understood, and that it has been taken into account when completing your application for ethical review.

Please be aware that whilst Health and Safety (H&S) issues may be considered during the ethical review process, you are still required to follow the University's guidance on H&S and to ensure that H&S risk assessments have been carried out as appropriate. For further information about this, please contact your School H&S representative or the University's H&S Unit at healthandsafety@contacts.bham.ac.uk.

Kind regards,

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Appendix 3B Reading Stimuli

Practice

1. McDonald's has reportedly admitted that its new paper straws, rolled out last year to help "protect the environment," can't be recycled — unlike the plastic versions they replaced. The straws were introduced to all 1,361 McDonald's restaurants in the United Kingdom and Ireland after a trial last year. But the fast food giant acknowledged on Monday that the new versions are too thick to be processed by its recyclers.
2. Apart from maintaining a healthy digestive system, scientists now claim that kimchi could be used to reverse hair loss as well. According to a story published in the Daily Mail, the Korean dish of fermented cabbage, onions, garlic, fish sauce and spices, which is known for its probiotic qualities can help regrow hair as well. Research shows that a kimchi drink sold in South Korea can help thicken existing hair and grow new ones in weeks.
3. The Covid-19 pandemic has been stressful in so many ways that it can be hard to separate the strands of what's getting us down or freaking us out. But amidst the health concerns, family worries, and social distancing strangeness, increased work stress certainly stands out as widespread consequence of the pandemic.
4. The COVID-19 pandemic has upended almost every aspect of our normal way of life: socializing, traveling, and even working in the office are mostly off-limits. But now the pandemic has put an end to another thing we've always taken for granted: quick Amazon deliveries.
5. Facebook plans to allow users to clean up their profiles by hiding posts and photographs dating from when they were teenagers or at university amid fears it could hinder their future job prospects. The social network said it had added the feature because "we know things change in people's lives" and that it wished to make it easier for people to "accurately reflect" who they were in the present.

Real experiment

1. Monaco became the first country in Europe to inaugurate a next-generation 5G mobile phone network based on technology from the Chinese firm Huawei, which is seen by the US as a major security risk. As mobile operators shift away from slower 3G and 4G networks, Europe has been torn over its approach to the Chinese giant, which is a pioneer in 5G technology.
2. Chinese scientists have completed the construction of a rover, which is planned to be used in the country's first mission to Mars in 2020, Chinese media reported, citing space experts. The planned mission includes orbiting, landing and moving on the surface of Mars, according to the Global Times newspaper. If the mission succeeds, scientists will be able to study the planet's atmosphere, as well as topographical, geological and magnetic field features, which will help to get a clue about the origin and evolution of Mars and the entire Solar System.
3. Chinese and Indian ethnic group workers have higher average earnings than their white British counterparts, the first detailed official figures show. But the data on the ethnicity pay gap, showed all other ethnic groups have lower wages than white British workers. The Office for National Statistics said employees in the Bangladeshi ethnic group have the largest pay gap, earning one fifth less than white British employees.

4. New Zealand has started charging an “admission fee” of about twenty pounds to overseas visitors. The International Visitor Conservation and Tourism Levy (IVL) came into effect on the first of July 2019. The tax applies to most foreign visitors. Citizens of Australia and some small Pacific nations are exempt, as are transit passengers. Crews on ships and aircraft will also dodge the levy. Tourism contributes one tenth of New Zealand’s GDP and employs over about a quarter of a million people.
5. Starting this week, over twenty four million permanent residents in Shanghai face a daily daunting test, and passing it is important. On Monday, Shanghai entered a new era of compulsory garbage sorting as the country wages war on a growing mountain of garbage to promote green growth and develop a circular economy. With a set of regulations coming into force, individuals, businesses and institutions in the city are ordered to sort garbage into four separate bins. The city is promoting a mandatory garbage sorting system, which requires residents to throw away garbage at a fixed time and place.
6. A new scientific study argues that the raised eyebrows, so beloved by dog owners, are more of a survival strategy than an expression of friendship. The clues, its authors argue, lie in a comparison with wolves, which dogs began evolving from after they were first domesticated by Stone Age men. Anatomical analysis reveals that while modern dogs have developed small muscles around the eyes which allows them to raise their inner eyebrows, wolves possess hardly any comparable muscles.
7. No matter how much stress you have at work, in your personal relationships, or countless other issues faced in daily life, it all just slips away when you lose yourself in a great story. A well-written novel can transport you to other realms, while an engaging article will distract you and keep you in the present moment, letting tensions drain away and allowing you to relax.
8. The key findings of a new report are that high-levels of Internet use could indeed impact on many functions of the brain. For example, the limitless stream of prompts and notifications from the Internet encourages us to constantly divide our attention which then in turn may decrease our capacity for maintaining concentration on a single task.
9. The Mayor of London Sadiq Khan has launched a £10 toxicity ‘T-Charge’ aimed at older, more polluting vehicles on London roads. The T-Charge, which went into force on the twenty third of October 2017, applies mainly to diesel and petrol vehicles registered before 2006, but also includes later models. You can check if your vehicle will be affected by the 'T-Charge' (or Emissions Surcharge) by using a free online vehicle checker.
10. It may not sound appetizing, but a new study found that the global average of microplastic ingestion could be five grams every week. That's about the same weight as a credit card. Put another way, it's a teaspoonful of plastic, two thousand tiny bits of plastic; you are inadvertently swallowing every single week, according to CNN.
11. The world's first 3D artificial eyeball may help people who are partially or fully blind in five years, according to experts. Researchers from Hong Kong University of Science and Technology have created an electrochemical eye whose structure and performance mimic those of the eyes humans are born with.
12. The number of international tourist arrivals will drop by 60-80% in 2020 due to the novel coronavirus pandemic, the World Tourism Organization said. Widespread travel restrictions and the closure of airports and national borders to limit the spread

of the virus have decreased international tourism into its worst crisis since records began in 1950, the UN tourism body said in a statement.

13. On Monday, one of Walt Disney Company's 14 closed theme parks, Shanghai Disneyland, reopened to visitors on a limited basis, offering a first peek into the kind of escape Mickey Mouse can offer in the age of face masks, social distancing and disinfectants. One of the new safety measures is phased reopening. This means Disney will begin by gradually and partially reopening certain locations, meaning retail and dining areas will likely open before theme parks.
14. When you read the headline 'Belgians urged to eat more fries' you may think it's a joke, but in Belgium, it was a serious request. The country's potato industry has been hit hard by COVID-19. When the virus began shutting down Italy, Spain and eventually Belgium, the crisis was in full swing, according to Romain Cools, the Secretary-General of Belgacom, which oversees Belgium's potato trade and processing industry.
15. Cars could soon be communicating with each other using 5G to make drivers aware of upcoming hazards, scientists claim. The ultra-fast mobile internet would allow for rapid information transmission and could make drivers aware of black ice, pot holes or other dangers up ahead. Several car manufacturers are already using 5G into their vehicles, including as a tool to help get to the generation of self-driving vehicles.
16. The royal family is joining the rest of the world in working from home during the coronavirus pandemic—and they're facing many of the same issues as the rest of us as they adjust to the new normal. During a rare interview with the BBC on Friday, Prince William and Kate Middleton revealed that their youngest son, Prince Louis, has been accidentally hanging up their video calls a lot lately.
17. In the upcoming sweltering summer heat in Japan, people will continue to wear masks to prevent the spread of the novel coronavirus. Several companies in different fields are hurrying to develop cool and dry face masks. Demand for masks suitable for summer use is increasing in Japan and other parts of the world. Medical experts warning against risks such as breathing difficulties and dehydration when people wear masks in the hot and humid season.
18. The world is widely considered to be on the edge of a fourth industrial revolution – one where machines will be able to do many of the jobs currently performed by humans, and perhaps even do them better. It is a future that promises greater efficiency and cheaper services, but one that also could cause widespread job losses.
19. You've probably heard that our oceans have become a plastic soup. But in fact, of all the plastic that enters Earth's oceans each year, just 1 percent has been observed floating on the surface. So where is the rest of it? This "missing" plastic has been a longstanding scientific question. To date, the search has focused on oceanic areas such as the Great Pacific Garbage Patch, the water column (the part of the ocean between the surface and the sea bed), the bottom of the ocean, and the stomachs of marine wildlife.
20. The level of air pollution in London, Rome, Milan and Paris has fallen sharply since coronavirus lockdown measures have forced people indoors and off the roads. Levels of small particles of dust, which can come from road transport and burning fuel, which comes primarily from vehicle exhausts, are low across London.
21. We all have our bad days. No one is going to wake up each and every morning in a happy mood. Sometimes we all feel just a little bit grumpier than usual, and that's just a part of being human. Yet once we get to the office, many in the workforce feel they must hide their emotions, whether it is frustration, anger, or sadness.

Interestingly, a new study finds keeping one's behaviour at the office authentic will result in greater productivity and a better relationship with co-workers. In other words: act how you feel, and don't fake it.

22. As Valentine's Day approaches, many people with dogs will not care one bit whether they get a card. A survey by the Kennel Club has found almost one in five would rather have a dog than be in a relationship. Almost half said they were so attached to their pet because 'dogs don't let you down' in the same way that other people might. Although a dog might not buy you roses or take you out for dinner, it seems unconditional love and a wagging tail can make being single a less lonely prospect.
23. Sometimes perhaps more than any other category of professionals, creative types are expected to enjoy brainstorms. In the public's imagination, their offices are filled with fidget toys and Post-it notes in an array of colours, all meant to absorb some of the energy of a group of fast-thinking, well-dressed hipsters deep in ideation mode. But a new report suggests that, in fact, a majority of these professionals find that brainstorming is largely unhelpful for solving a creative challenge.
24. Nowadays, to work remotely all you need is a computer and an internet connection. According to a new study, employees who can work from anywhere are generally happier than those who work onsite in an office. Video conferencing company Owl Labs surveyed 1202 full-time US workers from the ages of 22 to 65, and discovered that 62 percent of respondents worked remotely at least some of the time and 38 percent worked onsite. Of the remote workers, 49 percent worked remotely full-time.

Chinese stimuli

Practice

1. 为减少对环境的污染，英国和爱尔兰所有的麦当劳连锁店在二零零八年秋季不再使用塑料吸管转而使用纸制吸管。在新规定之前麦当劳公司称，仅英国一家店每天就扔掉一百八十万只塑料吸管。塑料吸管虽然可以回收处理，但是麦当劳公司还是用纸制吸管替代了它。麦当劳快餐连锁店的代表称："我们把纸制吸管做得太厚，因此尽管它的材料适合二次回收，但吸管的厚度暂时不允许对它进行溶解。我们正在解决这个问题。
2. 目前很多的生发药物都有副作用，但泡菜不同，它可以促进头发生长，逆转脱发，而且可以无限期食用且保证无副作用。研究人员表示，这种方法对患者来说是一种更安全的治疗策略。泡菜是韩国菜的主食，由发酵的卷心菜、洋葱、大蒜、鱼露和香料制成。致力于食用泡菜的倡导者还声称，泡菜可以降低人体胆固醇，清洁皮肤，甚至延缓衰老。二零一五年的一项研究还发现，泡菜和其他发酵食品可以减少年轻人的焦虑。
3. 新冠肺炎给人们带来了很多方面的压力，各种压力交织在一起，简直分不清是什么在导致我们感到沮丧或抓狂。这些压力当中，有对健康的忧虑，有对家庭的担心，也有社交隔离产生的陌生感，当然工作压力的增加作为疫情造成的一个普遍后果也很突出。
4. 新冠疫情已经影响到了我们正常生活的各个方面：社交、出行，甚至连在办公室工作几乎都被禁止了。但现在疫情毁掉了我们习以为常的另一件事：亚马逊快速配送。

5. 社交网络脸书将允许用户清理自己的个人资料，将青少年或大学时期上传的一些可能会阻碍求职前程的帖子和照片隐藏起来。脸书表示，增加这一功能是因为“我们知道人生会发生改变”，希望能有助于人们“准确地反映出”自己现在是个什么样的人。脸书称，公众可以运用“管理活动”工具，按年份或人物来搜索帖子，批量删除帖子或将其存档。

Real experiment

1. 摩纳哥在开通仪式上宣布：“我们是第一个完全 5G 网络覆盖的国家。”摩纳哥成为全世界第一个实现 5G 全覆盖的国家，这是该国主要运营商摩纳哥电信基于华为的技术实现的。要知道，早在去年摩纳哥就邀请华为为其搭建 5G 网络，达成合作，计划让摩纳哥成为欧洲第一个 5G 全覆盖的国家，结果成为了全球第一。
2. 在二零二零年也就是明年，中国将前往火星，这一次前往火星的目的可不仅仅只是简单的登陆，还包括多项科研探测任务。中国媒体报道中引用了航天专家的话，说中国科学家已做好探测器，计划用于我国二零二零年第一次火星任务中。据《环球时报》报道，这次已计划好的任务包括绕火星轨道运行，在火星表面着陆和移动。如果这次任务成功，科学家将能够研究火星的大气层、地形、地质和磁场特征，这有助于了解火星和整个太阳系的起源和演化。
3. 根据英国官方首次针对各族裔员工平均薪资所做的统计，华裔和印度裔员工的平均薪资比英国白人还高，其中华裔是收入最高的族裔，二零一八年平均收入比白人高出百分之三十点九。英国国家统计局表示，孟加拉裔员工与其他族裔的薪资差距最大，其收入比英国白人员工低百分之二十。但是，一旦把教育和职业等因素考虑进去，英国白人和其他大多数族裔之间的收入差距就会缩小，尽管差异依旧显著。
4. 七月一日起，来新西兰旅游的外国游客(澳大利亚游客除外)，将被征收额外的三十五新西兰元(约人民币一百六十元)/人的游客税，这笔钱在申请签证时缴纳。这笔游客税的全称为“国际游客保护和旅游税”，将用于新西兰自然资源的保护以及提升旅游相关基础设施建设。预计未来五年，将为新西兰政府带来超过四点五亿新西兰元的收入。
5. 《上海市生活垃圾管理条例》中，除对个人混投行为处五十元以上二百元以下罚款外，对单位未按照规定分类投放的行为，规定最高可处五万元的罚款。对生活垃圾收运单位、处置单位不遵守相应规范的，分别规定最高可处十万元、五十万元的罚款，情节严重的吊销单位经营服务许可证。另外，《条例》中还专门提出“促进源头减量”。其中明确规定，餐饮服务提供者和餐饮配送服务提供者不得主动向消费者提供一次性筷子、调羹等餐具。旅馆经营单位不得主动向消费者提供客房一次性日用品。
6. 狗的“无辜眼神”可能是为了萌化人类才进化出来的，显然这招很奏效。你知道你的狗狗想要某个东西时是故意做出那种表情的吗？你知道那种闪耀着渴望的乞求的眼神吗？她要什么你都愿意给，对吧？研究发现我们对犬类这种渴求或爱的眼神的回应可能导致狗狗有那种眼神。新的研究发现做这种表情牵动的面部肌肉只有狗狗有，狼就没有，这就表明我们的毛茸茸的好朋友专门为了跟人类沟通而进化出了这种能力。
7. 读一本有趣的书，当你沉浸于书中有趣的点子，或者和作者产生共鸣的时候，

那种有一座桥搭进心灵的感觉让人豁然开朗。这个时候生活中一切的烦恼和紧张都会被忘记，这也是很多书虫热爱读书的一个重要原因。读书越多的人，词汇量越大，逻辑越清晰，表达能力越强。结果是更加自信，在工作中和生活中能够得到更多的认可。

8. 一项关键的研究发现，那些强迫性地查看手机信息和其它通知的人，在面对干扰时保持注意力集中的某些脑前额叶外皮区域的大脑灰质减少了。因此，这些人在集中注意力的任务中表现得更差。另外，搜索引擎的影响也引起了人们的兴趣，我们可能有些过度依赖互联网作为信息来源，从而损害了我们自身的记忆能力。
9. 摆脱煤烟污染的困扰之后，"雾都"伦敦近年来又被另一种空气污染的阴霾所笼罩——汽车尾气。当地时间四月八日，为治理严重的汽车尾气污染，保障市民健康，伦敦开始在市中心区施行"超低排放区"，对尾气排放量超过标准的机动车额外收费，打响了治理空气污染的战争。有评论指出，此举一经实施将成为全球治理汽车排放最严厉的规定之一。伦敦市政府预期，未来两年内伦敦汽车尾气排放量有望减少百分之四十五。
10. 科学家首次证实人体正受到塑料微粒的污染。换句话说，塑料已经入侵到我们的身体中。活动人士说，当今塑料污染的程度之高意味着人们已经无法逃脱塑料的侵袭。而这些塑料污染物所含的有害化学物质无疑对人体、肠道以及免疫系统都会产生影响。研究小组负责人施瓦布表示，这一研究证实了他们长久以来的猜测。但关键是他们到底会给人类的健康带来怎样的影响，尤其是对胃肠疾病。
11. 专家称，世界首款 3D 人造眼球有望在五年内帮助许多部分或完全失明的人重见光明，这种人造眼球在某些方面比人眼还要好。香港科技大学的研究人员设计了一款模拟人眼结构和性能的电化学眼球。
12. 世界旅游组织表示，受新冠肺炎疫情影响，今年国际游客人数将减少六至八成。该联合国旅游机构在一份声明中称，为遏制病毒传播，多国实施旅行限制、关闭机场和边境等措施，使全球旅游业陷入自上世纪五十年代有记录以来的最大危机。
13. 周一，华特迪士尼公司 14 个被关闭的主题公园之一上海迪士尼乐园向游客限流重新开放，让人们首次窥探到了米老鼠在口罩、社交距离和消毒剂时代所能提供的那种逃离感。迪士尼的新安全措施之一是分阶段重新开放。这意味着迪士尼将逐步地重新开放部分园区的部分景点，这意味着零售和餐饮区很可能在主题乐园之前先开放。
14. 当你看到标题"比利时人被要求多吃薯条"，你可能会以为这是个玩笑，但在比利时，这是一个认真的请求。比利时的土豆产业遭到了新冠疫情的强烈冲击。比利时土豆贸易和加工行业监管机构的秘书长罗曼·库尔斯称，一开始病毒令意大利、西班牙采取封锁措施，最后比利时也进入封锁状态，导致土豆产业出现全面危机。
15. 科学家称，汽车很快就可以通过 5G 网络互相"对话"，让司机意识到前方的危险。超高速的移动互联网将使信息可以快速传输，并让司机意识到前方的黑冰、坑洞或其他危险。几家汽车制造商已经将 5G 网络技术融入汽车生产，包括以此来帮助引领自动驾驶汽车时代的到来。

16. 新冠疫情期间，皇室成员和世界上其他人一样在家办公，他们在适应这个新常态的过程中也和我们面临着很多同样的问题。在周五罕见的采访中，威廉王子和凯特·米德尔顿说他们最小的儿子路易斯王子最近多次无意中挂断他们的视频通话。
17. 日本不同行业的几家公司都在加紧研发凉爽干燥的口罩，以帮助人们应对即将到来的酷暑。为防止新冠病毒的传播，日本民众将继续佩戴口罩。在日本和世界其他地区，适合夏天使用的口罩需求正在增加。医学专家警告人们在湿热的季节戴口罩会带来呼吸困难和脱水等风险。
18. 很多人认为，世界即将迎来第四次工业革命——这一次，机器可以完成很多由人类负责的工作，甚至比人类做得更好。未来的世界可以实现更高的效率，享受更廉价的服务，但失业也将变得更加普遍。
19. 你可能已经听说了，我们的海洋里遍布塑料。但其实，每年进入海洋的塑料里，只有 1%被看到漂浮在海面上。那剩下的去哪儿了？“消失的”塑料是一个长期存在的科学问题。截至目前，搜寻的重点是海洋环流，比如大太平洋垃圾带、水柱（海洋表面和海床之间的部分）、海底和海洋动物的胃。
20. 在伦敦，来自公路运输和燃料燃烧的颗粒物，以及主要来自汽车尾气的二氧化氮的含量都很低。因新冠肺炎疫情封锁措施，多地民众被迫待在家中，不再上街，伦敦、罗马、米兰和巴黎的空气污染水平大幅下降。
21. 大家都有不顺心的时候。很少有人每天早上起床都是开开心心的。有时候我们觉得比平时更暴躁，但这也是人之常情。然而一旦我们踏进办公室，许多人就觉得有必要藏起自己的情绪，无论是感到绝望、生气还是悲伤。有趣的是，一项新研究发现，在办公室里表里如一能提高工作效率，还能改善和同事之间的关系。换言之，表露出内心感受，不要强装笑脸。
22. 情人节即将来临，但许多狗主人根本不在乎是否能收到贺卡。英国养犬俱乐部的一项调查发现，近五分之一的人宁愿养狗也不愿谈恋爱。近半数人说，他们如此依恋自己的狗狗，是因为“狗不会像其他人那样让你失望”。虽然狗狗可能不会给你买玫瑰或带你出去吃饭，但似乎无条件的爱和摇摆的尾巴可以让单身变得不那么孤单。
23. 也许和其他职业相比，创造性工作更应该是头脑风暴的活跃之地。在公众的想象里，创意人员的办公室里放满了抗压玩具和五颜六色的便条，这些都是用于从思维敏捷、衣着光鲜的创意人才那里吸取构思的能量。然而，一项报告显示，事实上，大多数创意人才发现头脑风暴对于解决创意难题基本没有帮助。
24. 现如今，要想远程工作，你只需要一台计算机并连上互联网。一项新研究发现，可以在任何地方工作的员工通常比待在办公室工作的员工更快乐。视频会议公司对 1202 名美国全职工作者进行了调查，发现 62％的受访者至少在某些时候会远程工作，而 38％的受访者只在办公室内工作。在远程工作者当中，有 49％的人全职远程工作。

Appendix 3C Comprehension Questions

One English reading text

Monaco became the first country in Europe to inaugurate a next-generation 5G mobile phone network based on technology from the Chinese firm Huawei, which is seen by the US as a major security risk. As mobile operators shift away from slower 3G and 4G networks, Europe has been torn over its approach to the Chinese giant, which is a pioneer in 5G technology.

Comprehension question

Is Huawei the Chinese pioneer in 5G technology?

Answer to the comprehension question

Yes

Appendix 3D Questionnaire for Chinese Participants

Language Questionnaire for Chinese Participants

1. Please enter your participant ID
2. Your age (in years)
3. Your gender

Male

Female

Prefer not to say

4. What degree are you currently pursuing?

Undergraduate

Masters

PhD

5. What degree are you studying for? (e.g., engineering, medicine, languages)
6. How long have you been staying in the UK (in months)?
7. When you write in Chinese, you do so in

Simplified Chinese

Traditional Chinese

Other

8. You first learned to read and write in Chinese using

Simplified Chinese

Traditional Chinese

Other

9. Is English your second language?

Yes

No

10. At what age were you first exposed to English?
11. At what age did you start reading in English?
12. How many years of formal education have you received in English?
13. If you have taken a standardised proficiency test for English (e.g., IELTS), please indicate the latest overall band score you received
14. If you have taken a standardised proficiency test for English (e.g., IELTS), please indicate the latest score you received for reading
15. If you have taken a standardised proficiency test for English (e.g., IELTS), please indicate the latest score you received for writing
16. If you have taken a standardised proficiency test for English (e.g., IELTS), please indicate the latest score you received for listening
17. If you have taken a standardised proficiency test for English (e.g., IELTS), please indicate the latest score you received for speaking
18. How long ago did you take your last IELTS test?

Appendix 3E Questionnaire for English Participants

Language Questionnaire for English Native Participants

1. Please enter your participant ID
2. Your age (in years)
3. Your gender

Male
Female
Prefer not to say

4. What degree are you currently pursuing?

Undergraduate
Masters
PhD

5. What degree are you studying for? (e.g., engineering, medicine, languages)
6. What is your native language? (If you are multilingual, please list all languages you use regularly.)
7. Have you learned any foreign languages?

Yes (please also answer the next question）
No (please skip the next question)

8. (Optional) If you have learned foreign languages, which ones and to what level (basic, intermediate, advanced)? (i.e., French, basic)
9. Do you speak Chinese? (If you, then you do not need to continue filling out this form.)

Appendix 3F Participants Grouping Result Based on Clustering Analysis

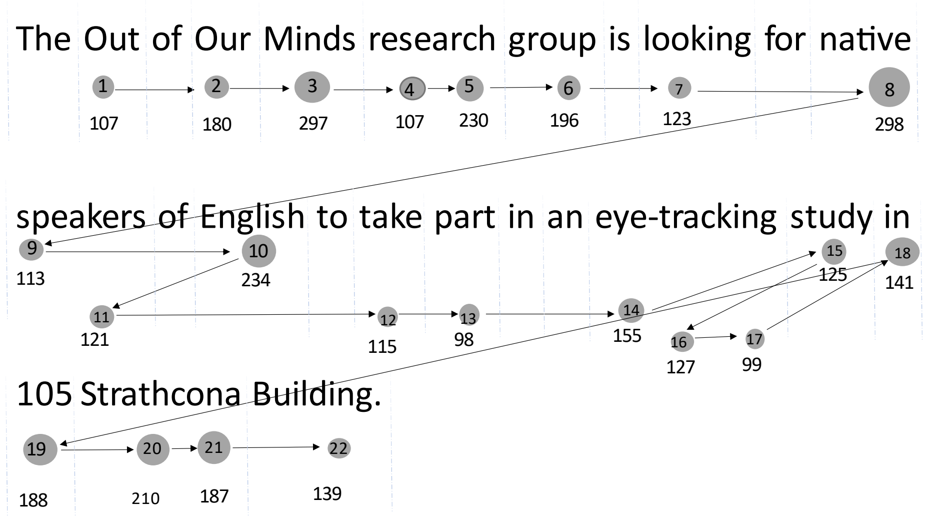
Participants grouping result based on clustering analysis

Participant_ID	Group	GroupOrder
CP1	Upper_Intermediate	Upper_Intermediate_ch
CP11	Upper_Intermediate	Upper_Intermediate_en
CP14	Upper_Intermediate	Upper_Intermediate_ch
CP15	Advanced	Advanced_en
CP17	Advanced	Advanced_ch
CP19	Upper_Intermediate	Upper_Intermediate_en
CP22	Advanced	Advanced_ch
CP23	Advanced	Advanced_en
CP25	Upper_Intermediate	Upper_Intermediate_ch
CP27	Upper_Intermediate	Upper_Intermediate_en
CP3	Upper_Intermediate	Upper_Intermediate_en
CP30	Advanced	Advanced_ch
CP31	Advanced	Advanced_en
CP35	Advanced	Advanced_en
CP39	Upper_Intermediate	Upper_Intermediate_en
CP6	Upper_Intermediate	Upper_Intermediate_ch
CP7	Upper_Intermediate	Upper_Intermediate_en
CP9	Advanced	Advanced_ch
CP33	Upper_Intermediate	Upper_Intermediate_ch
CP10	Advanced	Advanced_ch
CP12	Advanced	Advanced_en
CP13	Advanced	Advanced_ch
CP16	Advanced	Advanced_en
CP18	Upper_Intermediate	Upper_Intermediate_ch
CP2	Upper_Intermediate	Upper_Intermediate_ch
CP20	Advanced	Advanced_en

CP21	Upper_Intermediate	Upper_Intermediate_ch
CP24	Upper_Intermediate	Upper_Intermediate_en
CP26	Upper_Intermediate	Upper_Intermediate_ch
CP28	Upper_Intermediate	Upper_Intermediate_en
CP29	Upper_Intermediate	Upper_Intermediate_ch
CP32	Advanced	Advanced_en
CP34	Upper_Intermediate	Upper_Intermediate_ch
CP36	Advanced	Advanced_en
CP37	Advanced	Advanced_ch
CP4	Advanced	Advanced_en
CP40	Advanced	Advanced_en
CP5	Advanced	Advanced_ch
CP8	Upper_Intermediate	Upper_Intermediate_en

Appendix 3G Eye-movement Variables

A General Explanation about the Main Eye-Movement Variables used in This Study



Hypothetical eye-movements (fixations and saccades for a reader during silent reading). Each word is regarded as an Interest Area (IA) with dashed line separating them. Grey circles indicate fixations and arrows show saccades with various directions and lengths. Numbers (1-22) in circles show the order of fixations. Fixations are given in ms below the word on which they occurred for the purpose of presentation.

The figure above shows the main eye-movement measures and hypothetical patterns of eye movements in a sample sentence. Some of the most frequently used measures that have been included in this study include

- *IA first fixation duration.*
  The first fixation duration on an IA is the duration of the first fixation during the first pass over the word.
  In the figure above, the word 'research' has been fixated twice. Fixation 4 is the first fixation in that IA and the duration of that first fixation duration is 107ms. Similarly, the first fixation duration of the word 'speakers' on the second line is 113ms. The first fixation duration of word 'Strathcona' is 210ms.
- *IA first run dwell time.*
  The first run dwell time on an IA can also be called gaze duration. It is the sum of all fixations made in a word or region of interest before exiting the area or word either to the left or to the right.
  In the figure above, in the first pass, there are 2 fixations (fixation 4 and 5) on the IA of the word 'research'. The first run dwell time of word 'research' is the sum of fixation 4 and fixation 5, 107+230= 337ms. Similarly, the first run dwell time of the word 'Strathcona' is the sum of fixation 20 and fixation 21, which is 397ms.
- *IA dwell time*

Total reading time sums all fixations made within a region of text, including those fixations made when re-reading the region. For example, the word 'speakers' on the second line has 2 fixations. After fixation 9, the hypothetical reader made a second pass to word 'English', then made a following saccade back to 'speakers' and fixated on it, as fixation point 11 indicated. Therefore, the dwell time on IA/word 'speakers' is the sum of fixation 9 and 11, which is 234ms.

Let us focus on the word/IA 'eye-tracking'. There are 3 fixations in this IA. Fixation 14 is the first fixation, then, a saccade was made to the word 'study' following with a fixation (15) for 125ms. Then, the hypothetical reader fixated again on IA 'eye-tracking', fixation 16 and fixation 17. Therefore, the dwell time of IA 'eye-tracking' is the sum of three fixations (14+16+17), which is 381ms.

- *IA fixation counts*
  Fixation counts are the total number of all fixations done on a word or in an IA. For example, the fixation counts of the word 'Out' is 1, of the word 'research' is 2 and of the word 'eye-tracking' is 3.
- *IA skips*
  A word is skipped if there is no fixation on it. In our example, the words 'The', 'of', 'is', 'for', 'of', 'to', 'in', 'an' were skipped.
- *IA regression in counts*
  'Regression in counts' indicates how many times a regression from a later part of the sentence was made back into the current word/IA. For instance, there is 1 regression into word 'speaker' and 'eye-tracking' in the example.
- *IA Initial landing position*
  In this study, it is labelled as IA RelativeLandPos. It shows where the eyes first landed in an IA (X coordinate). The value is calculated as the Midpoint of the IA (X coordinate) minus the X position of the first fixation event within the current IA. If the value is greater than 0, the landing position is to the left of the centre of a word. If the value is smaller than 0, the landing position is to the right of the centre of a word. For example, the initial landing position on the word 'native' is towards the right of the centre and the initial landing position on word 'speakers', fixation 9 is towards the left of the centre of it.
- IA First saccade amplitude
  Saccade amplitude can be understood as the saccade length in this study. First saccade amplitude indicates the amplitude (in degrees of visual angle) of the first saccade entering the current interest area. As the arrows in the figure above present, saccades can be very short, such as the saccades within word 'research', 'eye-tracking' and 'Strathcona'. However, some saccades can be long, and an example can be found in-between fixation 7 and 8, and between fixation 11 and 12. Also, some saccades are longer since they are caused by crossline reading events, such as two long saccades between fixation 8 and 9, and fixation 18 and fixation 19.

Appendix 4 English Reading Study
Effect of Variables on First Fixation Duration

Predictors	*Estimates*	*CI*	*p*
(Intercept)	6.847	6.693 – 7.001	**<0.001**
GroupOrder [Advanced ENG first]	0.079	-0.123 – 0.280	0.444
GroupOrder [Native English]	-0.365	-0.533 – -0.197	**<0.001**
GroupOrder [Upper CH first]	0.013	-0.188 – 0.215	0.896
GroupOrder [Upper ENG first]	0.049	-0.162 – 0.259	0.649
GroupOrder [Advanced CH first] × oly(Scaled Word Story Order, 3)1	-2.687	-7.854 – 2.480	0.308
GroupOrder [Advanced ENG first] × oly (Scaled Word Story Order, 3)1	-0.575	-4.744 – 3.595	0.787
GroupOrder [NativeEnglish] × poly(Scaled Word Story Order, 3)1	-5.610	-8.388 – -2.833	**<0.001**
GroupOrder [Upper CHfirst] × oly(Scaled Word Story Order, 3)1	3.516	-0.628 – 7.661	0.096
GroupOrder [Upper ENG first] × oly(Scaled Word Story Order, 3)1	-2.298	-6.801 – 2.204	0.317
GroupOrder [Advanced CH first] × oly(Scaled Word Story Order, 3)2	-2.946	-8.776 – 2.884	0.322
GroupOrder [Advanced ENG first] × oly(Scaled Word Story Order, 3)2	-3.858	-8.822 – 1.106	0.128
GroupOrder [Native English] × poly(Scaled Word Story Order, 3)2	2.637	-1.304 – 6.578	0.190
GroupOrder [Upper CH first] × poly(Scaled Word Story Order, 3)2	-2.856	-7.802 – 2.089	0.258
GroupOrder [Upper ENG first] × poly(Scaled Word Story Order, 3)2	-3.711	-8.934 – 1.512	0.164
GroupOrder [Advanced CH first] × oly(Scaled Word Story Order, 3)3	3.125	-2.029 – 8.279	0.235
GroupOrder [Advanced ENG first] × oly(Scaled Word Story Order, 3)3	-4.946	-9.122 – -0.771	**0.020**
GroupOrder [Native English] × poly(Scaled Word Story Order, 3)3	1.848	-0.930 – 4.625	0.192
GroupOrder [Upper CH first] × poly(Scaled Word Story Order, 3)3	-3.411	-7.553 – 0.730	0.106
GroupOrder [Upper ENG first] × poly(Scaled Word Story Order, 3)3	-1.963	-6.453 – 2.527	0.391
GroupOrder [Advanced CH first] × poly(Wordlength N, 3)1	26.451	18.041 – 34.861	**<0.001**
GroupOrder [Advanced ENG first] × poly (Wordlength N, 3)1	21.843	14.674 – 29.012	**<0.001**
GroupOrder [Native English]	16.936	11.280 – 22.593	**<0.001**

× Poly (Wordlength N, 3)1			
GroupOrder [Upper CH first] × poly(Wordlength N, 3)1	20.640	13.441 – 27.838	**<0.001**
GroupOrder [Upper ENG first] × poly(Wordlength N, 3)1	16.213	8.596 – 23.831	**<0.001**
GroupOrder [Advanced CH first] × poly(Wordlength N, 3)2	-12.950	-19.864 – -6.037	**<0.001**
GroupOrder [Advanced ENG first] × poly (Wordlength N, 3)2	-14.362	-20.331 – -8.393	**<0.001**
GroupOrder [Native English] × poly(Wordlength N, 3)2	-4.784	-9.514 – -0.053	**0.047**
GroupOrder [Upper CH first] × poly(Wordlength N, 3)2	-12.205	-18.187 – -6.223	**<0.001**
GroupOrder [Upper ENG first] × poly(Wordlength N, 3)2	-12.425	-18.770 – -6.080	**<0.001**
GroupOrder [Advanced CH first] × poly(Wordlength N, 3)3	-0.541	-6.734 – 5.652	0.864
GroupOrder [Advanced ENG first] × poly (Wordlength N, 3)3	0.087	-5.349 – 5.523	0.975
GroupOrder [Native English] × poly(Wordlength N, 3)3	0.217	-3.823 – 4.258	0.916
GroupOrder [Upper CH first] × poly(Wordlength N, 3)3	10.019	4.610 – 15.427	**<0.001**
GroupOrder [Upper ENG first] × poly(Wordlength N, 3)3	5.311	-0.272 – 10.895	0.062
GroupOrder [Advanced CH first] × poly(Fre log N, 2)1	-27.144	-36.671 – -17.617	**<0.001**
GroupOrder [Advanced ENG first] × poly(Fre log N,2)1	-31.442	-39.824 – -23.060	**<0.001**
GroupOrder [Native English] × poly(Fre log N, 2)1	-17.341	-24.520 – -10.163	**<0.001**
GroupOrder [Upper CH first] × poly(Fre log N,2)1	-19.792	-28.186 – -11.397	**<0.001**
GroupOrder [Upper ENG first] × poly(Fre log N,2)1	-21.686	-30.379 – -12.992	**<0.001**
GroupOrder [Advanced CH first] × poly(Fre log N,2)2	-21.273	-28.841 – -13.705	**<0.001**
GroupOrder [Advanced ENG first] × poly(Fre log N,2)2	-20.629	-27.318 – -13.939	**<0.001**
GroupOrder [Native English] × poly(Fre log N, 2)2	-10.841	-16.514 – -5.169	**<0.001**
GroupOrder [Upper CH first] × poly(Fre log N, 2)2	-18.092	-24.777 – -11.407	**<0.001**
GroupOrder [Upper ENG first] × poly(Fre log N, 2)2	-14.807	-21.785 – -7.828	**<0.001**
GroupOrder [Advanced CH first] × poly	-4.629	-12.666 – 3.409	0.259

(Wordlength Prev, 3)1			
GroupOrder [Advanced ENG first] × poly (Wordlength Prev, 3)1	-0.207	-6.788 – 6.374	0.951
GroupOrder [Native English] × poly (Wordlength Prev, 3)1	3.737	-0.989 – 8.464	0.121
GroupOrder [Upper CH first] × poly(Wordlength Prev, 3)1	-0.255	-6.794 – 6.283	0.939
GroupOrder [Upper ENG first] × poly(Wordlength Prev, 3)1	-11.710	-18.756 – -4.663	**0.001**
GroupOrder [Advanced CH first] × poly(Wordlength Prev, 3)2	9.336	3.344 – 15.328	**0.002**
GroupOrder [Advanced ENG first] × poly (Wordlength Prev, 3)2	2.887	-2.012 – 7.786	0.248
GroupOrder [Native English] ×poly (Wordlength Prev, 3)2	5.692	2.138 – 9.246	**0.002**
GroupOrder [Upper CH first] × poly(Wordlength Prev, 3)2	1.028	-3.844 – 5.899	0.679
GroupOrder [Upper ENG first] × poly(Wordlength Prev, 3)2	8.928	3.665 – 14.191	**0.001**
GroupOrder [Advanced CH first] × poly(Wordlength Prev, 3)3	-4.674	-10.202 – 0.854	0.097
GroupOrder [Advanced ENG first] × poly (Wordlength Prev, 3)3	-3.297	-7.601 – 1.008	0.133
GroupOrder [Native English] ×poly(Wordlength Prev, 3)3	0.345	-2.829 – 3.518	0.831
GroupOrder [Upper CH first] × poly(Wordlength Prev, 3)3	-0.478	-4.766 – 3.809	0.827
GroupOrder [Upper ENG first] × poly(Wordlength Prev, 3)3	-6.587	-11.230 – -1.943	**0.005**
GroupOrder [Advanced CH first] × poly(Fre log Prev, 2)1	0.636	-7.507 – 8.779	0.878
GroupOrder [Advanced ENG first] × poly(Fre log Prev, 2)1	-2.842	-9.572 – 3.888	0.408
GroupOrder [Native English] × poly(Fre log Prev, 2)1	1.049	-3.790 – 5.888	0.671
GroupOrder [Upper CH first] × poly(Fre log rev, 2)1	-5.449	-12.120 – 1.222	0.109
GroupOrder [Upper ENG first] × poly(Fre log Prev, 2)1	-7.993	-15.138 – -0.848	**0.028**
GroupOrder [Advanced CH first] × poly(Fre log Prev, 2)2	0.741	-5.306 – 6.789	0.810
GroupOrder [Advanced ENG first] × poly(Fre log Prev, 2)2	-7.581	-12.568 – -2.594	**0.003**

GroupOrder [Native English] × poly(Fre logPrev, 2)2	4.083	0.458 – 7.708	**0.027**
GroupOrder [Upper CH first] × poly(Fre log Prev, 2)2	1.374	-3.602 – 6.351	0.588
GroupOrder [Upper ENG first] × poly(Fre log Prev, 2)2	-6.951	-12.323 – -1.578	**0.011**

Appendix 5 English Reading Study
Effect of Variables on Gaze Duration

Predictors	*Estimates*	*CI*	*p*
(Intercept)	1.715	1.707 – 1.722	<0.001
GroupOrder [Advanced CH first]	0.038	0.020 – 0.055	<0.001
GroupOrder [Advanced ENG first]	0.047	0.032 – 0.062	<0.001
GroupOrder [Upper CH first]	0.051	0.036 – 0.066	<0.001
GroupOrder [Upper ENG first]	0.066	0.050 – 0.083	<0.001
GroupOrder [Native English] × poly(Scaled Word Story Order, 3)1	-0.469	-0.714 – -0.225	<0.001
GroupOrder [Advanced CH first] × poly(Scaled Word Story Order, 3)1	-0.433	-0.888 – 0.022	0.062
GroupOrder [Advanced ENG first] × poly(Scaled Word Story Order, 3)1	0.215	-0.152 – 0.583	0.251
GroupOrder [Upper CH first] × poly(Scaled Word Story Order, 3)1	0.377	0.012 – 0.742	0.043
GroupOrder [Upper ENG first] × poly(Scaled Word Story Order, 3)1	-0.556	-0.953 – -0.159	0.006
GroupOrder [Native English] × poly(Scaled Word Story Order, 3)2	0.403	0.051 – 0.756	0.025
GroupOrder [Advanced CH first] × poly(Scaled Word Story Order, 3)2	-0.108	-0.625 – 0.410	0.683
GroupOrder [Advanced ENG first] × poly(Scaled Word Story Order, 3)2	-0.199	-0.640 – 0.243	0.378
GroupOrder [Upper CH first] × poly(Scaled Word Story Order, 3)2	-0.342	-0.781 – 0.098	0.127
GroupOrder [Upper ENG first] × poly(Scaled Word Story Order, 3)2	-0.492	-0.955 – -0.028	0.038
GroupOrder [Native English] × poly(Scaled Word Story Order, 3)3	0.067	-0.178 – 0.312	0.591
GroupOrder [Advanced CH first] × poly(Scaled Word Story Order, 3)3	-0.283	-0.737 – 0.171	0.222
GroupOrder [Advanced ENG first] × poly(Scaled Word Story Order, 3)3	-0.519	-0.887 – -0.151	0.006
GroupOrder [Upper CH first] × poly(Scaled Word Story Order, 3)3	-0.255	-0.620 – 0.110	0.171
GroupOrder [Upper ENG first] × poly(Scaled Word Story Order, 3)3	-0.370	-0.766 – 0.025	0.066
GroupOrder [Native English] ×poly(Wordlength N, 2)1	4.720	4.161 – 5.280	<0.001
GroupOrder [Advanced CH first] × poly(Wordlength N, 2)1	7.265	6.483 – 8.047	<0.001
GroupOrder [Advanced ENG first] × poly (Wordlength N, 2)1	7.343	6.661 – 8.026	<0.001
GroupOrder [Upper CH first]	8.390	7.705 – 9.075	<0.001

× poly(Wordlength N, 2)1			
GroupOrder [Upper ENG first] × poly(Wordlength N, 2)1	9.691	8.971 – 10.412	<0.001
GroupOrder [Native English] × poly(Wordlength N, 2)2	0.012	-0.447 – 0.470	0.961
GroupOrder [Advanced CH first] × poly(Wordlength N, 2)2	-0.774	-1.415 – -0.132	0.018
GroupOrder [Advanced ENG first] × poly (Wordlength N, 2)2	-0.467	-1.033 – 0.098	0.105
GroupOrder [Upper CH first] × poly(Wordlength N, 2)2	-1.266	-1.833 – -0.700	<0.001
GroupOrder [Upper ENG first] × poly(Wordlength N, 2)2	-1.516	-2.112 – -0.920	<0.001
GroupOrder [Native English] × poly(Fre logN, 3)1	-1.815	-2.698 – -0.932	<0.001
GroupOrder [Advanced CH first] × poly(Fre log N, 3)1	-2.890	-3.931 – -1.848	<0.001
GroupOrder [Advanced ENG first] × poly(Fre log N,3)1	-3.560	-4.522 – -2.598	<0.001
GroupOrder [Upper CH first] × poly(Fre log N, 3)1	-2.555	-3.518 – -1.593	<0.001
GroupOrder [Upper ENG first] × poly(Fre log N, 3)1	-3.783	-4.767 – -2.800	<0.001
GroupOrder [Native English] × poly(Fre log N, 3)2	-0.500	-1.232 – 0.232	0.181
GroupOrder [Advanced CH first] × poly(Fre log N, 3)2	-1.139	-1.995 – -0.284	0.009
GroupOrder [Advanced ENG first] × poly(Fre log N,3)2	-1.149	-1.944 – -0.354	0.005
GroupOrder [Upper CH first] × poly(Fre log N, 3)2	-1.273	-2.068 – -0.477	0.002
GroupOrder [Upper ENG first] × poly(Fre log N, 3)2	-1.154	-1.968 – -0.340	0.005
GroupOrder [Native English] × poly(Fre log N, 3)3	0.213	-0.340 – 0.766	0.450
GroupOrder [Advanced CH first] × poly(Fre log N, 3)3	0.375	-0.298 – 1.048	0.275
GroupOrder [Advanced ENG first] × poly(Fre log N,3)3	0.327	-0.293 – 0.947	0.301
GroupOrder [Upper CH first] × poly(Fre log N, 3)3	0.322	-0.297 – 0.940	0.308
GroupOrder [Upper ENG first] × poly(Fre log N, 3)3	1.025	0.385 – 1.664	0.002
GroupOrder [Native English] × poly(Wordlength Prev, 3)1	-0.394	-0.826 – 0.037	0.073
GroupOrder [Advanced CH first] × poly(Wordlength Prev, 3)1	-1.380	-2.098 – -0.662	<0.001

GroupOrder [Advanced ENG first] × poly (Wordlength Prev, 3)1	-0.748	-1.338 – -0.157	0.013
GroupOrder [Upper CH first] × poly(Wordlength Prev, 3)1	-0.636	-1.222 – -0.049	0.034
GroupOrder [Upper ENG first] × poly(Wordlength Prev, 3)1	-1.654	-2.284 – -1.023	<0.001
GroupOrder [Native English] × poly(Wordlength Prev, 3)2	0.644	0.319 – 0.969	<0.001
GroupOrder [Advanced CH first] × poly(Wordlength Prev, 3)2	1.325	0.790 – 1.860	<0.001
GroupOrder [Advanced ENG first] × poly (Wordlength Prev, 3)2	0.485	0.046 – 0.925	0.031
GroupOrder [Upper CH first] × poly(Wordlength Prev, 3)2	0.787	0.350 – 1.224	<0.001
GroupOrder [Upper ENG first] × poly(Wordlength Prev, 3)2	1.159	0.688 – 1.630	<0.001
GroupOrder [Native English] ×poly (Wordlength Prev, 3)3	0.328	0.038 – 0.618	0.027
GroupOrder [Advanced CH first] × poly(Wordlength Prev, 3)3	-0.071	-0.565 – 0.422	0.776
GroupOrder [Advanced ENG first] × poly (Wordlength Prev, 3)3	-0.250	-0.636 – 0.136	0.205
GroupOrder [Upper CH first] × poly(Wordlength Prev, 3)3	-0.133	-0.518 – 0.251	0.496
GroupOrder [Upper ENG first] × poly(Wordlength Prev, 3)3	-0.735	-1.150 – -0.320	0.001
GroupOrder [Native English] × poly(Wordlength Next, 2)1	-0.524	-0.963 – -0.086	0.019
GroupOrder [Advanced CH first] × poly(Wordlength Next, 2)1	-0.749	-1.489 – -0.010	0.047
GroupOrder [Advanced ENG first] × poly	-1.005	-1.612 – -0.397	0.001
(Wordlength Next, 2)1			
GroupOrder [Upper CH first] × poly(Wordlength Next, 2)1	-0.669	-1.270 – -0.069	0.029
GroupOrder [Upper ENG first] × poly(Wordlength Next, 2)1	-0.791	-1.433 – -0.149	0.016
GroupOrder [Native English] × poly(Wordlength Next, 2)2	-0.032	-0.354 – 0.290	0.845
GroupOrder [Advanced CH first] × poly(Wordlength Next, 2)2	0.532	0.007 – 1.058	0.047
GroupOrder [Advanced ENG first] × poly (Wordlength Next, 2)2	0.364	-0.070 – 0.798	0.100
GroupOrder [Upper CH first] × poly(Wordlength Next, 2)2	0.429	-0.005 – 0.863	0.053
GroupOrder [Upper ENG first] × poly(Wordlength Next, 2)2	0.516	0.056 – 0.977	0.028

GroupOrder [Native English] × poly(Fre log Prev, 2)1	-0.069	-0.513 – 0.376	0.762
GroupOrder [Advanced CH first] × poly(Fre log Prev, 2)1	-0.354	-1.082 – 0.375	0.342
GroupOrder [Advanced ENG first] × poly(Fre log Prev, 2)1	-0.301	-0.907 – 0.305	0.330
GroupOrder [Upper CH first] × poly(Fre log Prev, 2)1	-0.505	-1.106 – 0.096	0.099
GroupOrder [Upper ENG first] × poly(Fre log Prev, 2)1	-1.167	-1.808 – -0.525	<0.001
GroupOrder [Native English] × poly(Fre log Prev, 2)2	0.422	0.089 – 0.755	0.013
GroupOrder [Advanced CH first] × poly(Fre log Prev, 2)2	-0.207	-0.749 – 0.336	0.455
GroupOrder [Advanced ENG first] × poly(Fre log Prev, 2)2	-0.102	-0.551 – 0.347	0.656
GroupOrder [Upper CH first] × poly(Fre log Prev, 2)2	0.007	-0.441 – 0.456	0.974
GroupOrder [Upper ENG first] × poly(Fre log Prev, 2)2	-0.436	-0.919 – 0.046	0.076
GroupOrder [Native English] × poly(Fre log Next, 3)1	-0.101	-0.542 – 0.340	0.653
GroupOrder [Advanced CH first] × poly(Fre log Next, 3)1	-0.214	-0.954 – 0.527	0.572
GroupOrder [Advanced ENG first] × poly(Fre log Next, 3)1	-0.008	-0.618 – 0.602	0.981
GroupOrder [Upper CHfirst] × poly(Fre logNext, 3)1	0.051	-0.555 – 0.657	0.870
GroupOrder [Upper ENG first] × poly(Fre log Next, 3)1	0.629	-0.015 – 1.273	0.056
GroupOrder [Native English] × poly(Fre log Next, 3)2	-0.433	-0.754 – -0.113	0.008
GroupOrder [Advanced CH first] × poly(Fre log Next, 3)2	0.014	-0.524 – 0.552	0.958
GroupOrder [Advanced ENG first] × poly(Fre log Next, 3)2	-0.204	-0.648 – 0.240	0.369
GroupOrder [Upper CH first] × poly(Fre log Next, 3)2	-0.293	-0.732 – 0.146	0.190
GroupOrder [Upper ENG first] × poly(Fre log Next, 3)2	-0.173	-0.642 – 0.296	0.470
GroupOrder [Native English] × poly(Fre log Next, 3)3	0.348	0.061 – 0.634	0.018
GroupOrder [Advanced CH first] × poly(Fre log Next, 3)3	0.520	0.036 – 1.005	0.035
GroupOrder [Advanced ENG first] × poly(Fre log Next, 3)3	-0.227	-0.624 – 0.171	0.264
GroupOrder [Upper CH first] × poly(Fre log Next, 3)3	0.045	-0.349 – 0.440	0.822

GroupOrder [Upper ENG first] × poly(Fre log Next, 3)3	0.250	-0.170 – 0.670	0.244

Appendix 6 English Reading Study
Effect of Variables on Total Reading Time

Predictors	*Estimates*	*CI*	*p*
(Intercept)	5.489	5.435 – 5.543	**<0.001**
GroupOrder [Advanced CH first]	0.188	0.064 – 0.313	**0.003**
GroupOrder [Advanced ENG first]	0.319	0.209 – 0.429	**<0.001**
GroupOrder [Upper CH first]	0.302	0.192 – 0.412	**<0.001**
GroupOrder [Upper ENG first]	0.421	0.302 – 0.540	**<0.001**
GroupOrder [Native English] × poly(Scaled Word Story Order, 3)1	-4.972	-6.588 – -3.356	**<0.001**
GroupOrder [Advanced CH first] × poly(Scaled Word Story Order, 3)1	-4.542	-7.546 – -1.538	**0.003**
GroupOrder [Advanced ENG first] × poly(Scaled Word Story Order, 3)1	-4.253	-6.681 – -1.826	**0.001**
GroupOrder [Upper CH first] × poly(Scaled Word Story Order, 3)1	1.301	-1.109 – 3.711	0.290
GroupOrder [Upper ENG first] × poly(Scaled Word Story Order, 3)1	-4.635	-7.259 – -2.010	**0.001**
GroupOrder [Native English] × poly(Scaled Word Story Order, 3)2	3.627	-0.525 – 7.779	0.087
GroupOrder [Advanced CH first] × poly(Scaled Word Story Order, 3)2	2.491	-2.350 – 7.332	0.313
GroupOrder [Advanced ENG first] × poly(Scaled Word Story Order, 3)2	0.234	-4.267 – 4.734	0.919
GroupOrder [Upper CH first] × poly(Scaled Word Story Order, 3)2	-1.589	-6.081 – 2.903	0.488
GroupOrder [Upper ENG first] × poly(Scaled Word Story Order, 3)2	-0.747	-5.342 – 3.847	0.750
GroupOrder [Native English] × poly(Scaled Word Story Order, 3)3	-0.513	-2.128 – 1.102	0.533
GroupOrder [Advanced CH first] × poly(Scaled Word Story Order, 3)3	-4.808	-7.804 – -1.811	**0.002**
GroupOrder [Advanced ENG first] × poly(Scaled Word Story Order, 3)3	1.185	-1.246 – 3.615	0.339
GroupOrder [Upper CH first] × poly(Scaled Word Story Order, 3)3	-3.756	-6.164 – -1.348	**0.002**
GroupOrder [Upper ENG first] × poly(Scaled Word Story Order, 3)3	-1.068	-3.684 – 1.547	0.423
GroupOrder [Native English] × poly(Wordlength N, 3)1	38.369	34.237 – 42.500	**<0.001**
GroupOrder [Advanced CH first] × poly(Wordlength N, 3)1	54.531	49.038 – 60.024	**<0.001**
GroupOrder [Advanced ENG first] × poly (Wordlength N, 3)1	53.337	48.477 – 58.198	**<0.001**
GroupOrder [Upper CH first] × poly(Wordlength N, 3)1	58.189	53.312 – 63.066	**<0.001**

GroupOrder [Upper ENG first] × poly(Wordlength N, 3)1	67.077	61.992 – 72.162	**<0.001**
GroupOrder [Native English] × poly(Wordlength N, 3)2	-3.061	-6.577 – 0.455	0.088
GroupOrder [Advanced CH first] × poly(Wordlength N, 3)2	-6.437	-11.015 – -1.860	**0.006**
GroupOrder [Advanced ENG first] × poly (Wordlength N, 3)2	-7.502	-11.605 – -3.398	**<0.001**
GroupOrder [Upper CH first] × poly(Wordlength N, 3)2	-8.599	-12.711 – -4.488	**<0.001**
GroupOrder [Upper ENG first] × poly(Wordlength N, 3)2	-9.402	-13.694 – -5.111	**<0.001**
GroupOrder [Native English] × poly(Wordlength N, 3)3	2.938	-0.071 – 5.947	0.056
GroupOrder [Advanced CH first] × poly(Wordlength N, 3)3	2.543	-1.519 – 6.605	0.220

GroupOrder [Advanced ENG first] × poly (WordlengthN, 3)3	1.962	-1.721 – 5.645	0.296
GroupOrder [Upper CH first] × poly(Wordlength N, 3)3	4.461	0.791 – 8.131	**0.017**
GroupOrder [Upper ENG first] × poly(Wordlength N, 3)3	2.740	-1.012 – 6.491	0.152
GroupOrder [Native English] × poly(Fre log N,2)1	-16.417	-21.958 – -10.877	**<0.001**
GroupOrder [Advanced CH first] × poly(Fre log N,2)1	-20.279	-26.906 – -13.652	**<0.001**
GroupOrder [Advanced ENG first] × poly(Fre log N,2)1	-25.576	-31.662 – -19.491	**<0.001**
GroupOrder [Upper CH first] × poly(Fre log N,2)1	-19.744	-25.835 – -13.652	**<0.001**
GroupOrder [Upper ENG first] × poly(Fre log N,2)1	-27.562	-33.792 – -21.331	**<0.001**

GroupOrder [Native English] × poly(Fre log N,2)2	-2.180	-6.559 – 2.200	0.329
GroupOrder [Advanced CH first] × poly(Fre log N,2)2	-6.681	-11.961 – -1.400	**0.013**
GroupOrder [Advanced ENG first] × poly(Fre log N,2)2	-6.893	-11.744 – -2.041	**0.005**
GroupOrder [Upper CH first] × poly(Fre log N,2)2	-8.320	-13.171 – -3.470	**0.001**
GroupOrder [Upper ENG first] × poly(Fre log N,2)2	-8.478	-13.469 – -3.487	**0.001**
GroupOrder [Native English] × poly(Wordlength Prev, 2)1	-9.516	-12.194 – -6.838	**<0.001**
GroupOrder [Advanced CH first] × poly(Wordlength Prev, 2)1	-11.895	-16.343 – -7.447	**<0.001**
GroupOrder [Advanced ENG first] × poly (Wordlength Prev, 2)1	-12.972	-16.620 – -9.325	**<0.001**

GroupOrder [Upper CH first] × poly(Wordlength Prev, 2)1	-9.695	-13.302 – -6.087	**<0.001**
GroupOrder [Upper ENG first] × poly(Wordlength Prev, 2)1	-15.678	-19.563 – -11.793	**<0.001**
GroupOrder [Native English] ×poly (Wordlength Prev, 2)2	5.531	3.502 – 7.560	**<0.001**
GroupOrder [Advanced CH first] × poly(Wordlength Prev, 2)2	7.290	3.967 – 10.613	**<0.001**
GroupOrder [Advanced ENG first] × poly (Wordlength Prev, 2)2	1.408	-1.321 – 4.137	0.312
GroupOrder [Upper CH first] × poly(Wordlength Prev, 2)2	5.738	3.039 – 8.436	**<0.001**
GroupOrder [Upper ENG first] × poly(Wordlength Prev, 2)2	4.255	1.339 – 7.170	**0.004**
GroupOrder [Native English] ×poly(Wordlength Next, 2)1	-5.941	-8.874 – -3.009	**<0.001**
GroupOrder [Advanced CH first] × poly(Wordlength Next, 2)1	-6.197	-11.105 – -1.289	**0.013**
GroupOrder [Advanced ENG first] × poly (Wordlength Next, 2)1	-9.859	-13.897 – -5.821	**<0.001**
GroupOrder [Upper CH first] × poly(Wordlength Next, 2)1	-5.145	-9.135 – -1.156	**0.011**
GroupOrder [Upper ENG first] × poly(Wordlength Next, 2)1	-5.779	-10.041 – -1.518	**0.008**
GroupOrder [Native English] ×poly(Wordlength Next, 2)2	1.110	-1.039 – 3.259	0.311
GroupOrder [Advanced CH first] × poly(Wordlength Next, 2)2	4.219	0.740 – 7.699	**0.017**
GroupOrder [Advanced ENG first] × poly (Wordlength Next, 2)2	2.580	-0.299 – 5.460	0.079
GroupOrder [Upper CH first] × poly(Wordlength Next, 2)2	3.706	0.826 – 6.585	**0.012**
GroupOrder [Upper ENG first] × poly(Wordlength Next, 2)2	1.745	-1.306 – 4.796	0.262
GroupOrder [Native English] × Fre log Prev	-0.023	-0.033 – -0.013	**<0.001**
GroupOrder [Advanced CH first] × Fre log Prev	-0.015	-0.031 – 0.001	0.073
GroupOrder [Advanced ENG first] × Fre log Prev	-0.027	-0.041 – -0.014	**<0.001**
GroupOrder [Upper CHfirst] × Fre log Prev	-0.017	-0.030 – -0.004	**0.011**
GroupOrder [Upper ENG first] × Fre log Prev	-0.036	-0.050 – -0.021	**<0.001**
GroupOrder [Native English] × poly(Fre log Next, 3)1	-4.676	-7.626 – -1.727	**0.002**

GroupOrder [Advanced CH first] × poly(Fre log Next, 3)1	-4.558	-9.464 – 0.348	0.069
GroupOrder [Advanced ENG first] × poly(Fre log Next, 3)1	-1.580	-5.631 – 2.471	0.445
GroupOrder [Upper CH first] × poly(Fre log Next, 3)1	-2.171	-6.196 – 1.855	0.291
GroupOrder [Upper ENG first] × poly(Fre log Next, 3)1	0.050	-4.222 – 4.321	0.982
GroupOrder [Native English] × poly(Fre log Next, 3)2	-2.918	-5.063 – -0.772	**0.008**
GroupOrder [Advanced CH first] × poly(Fre log Next, 3)2	0.103	-3.462 – 3.669	0.955
GroupOrder [Advanced ENG first] × poly(Fre log Next, 3)2	-2.694	-5.645 – 0.256	0.073
GroupOrder [Upper CH first] × poly(Fre log Next, 3)2	-2.142	-5.056 – 0.773	0.150
GroupOrder [Upper ENG first] × poly(Fre log Next, 3)2	-3.002	-6.112 – 0.108	0.059
GroupOrder [Native English] × poly(Fre log Next, 3)3	3.584	1.671 – 5.496	**<0.001**
GroupOrder [Advanced CH first] × poly(Fre log Next, 3)3	1.032	-2.172 – 4.236	0.528
GroupOrder [Advanced ENG first] × poly(Fre log Next, 3)3	0.226	-2.406 – 2.858	0.866
GroupOrder [Upper CH first] × poly(Fre log Next, 3)3	-0.846	-3.460 – 1.767	0.526
GroupOrder [Upper ENG first] × poly(Fre log Next, 3)3	0.611	-2.170 – 3.393	0.667

Appendix 8 Chinese Reading Study
Effect of Variables on First Fixation Duration

Predictors	*Estimates*	*CI*	*p*
(Intercept)	2.406	2.378 – 2.435	**<0.001**
GroupOrder [Advanced_en]	0.004	-0.033 – 0.041	0.837
GroupOrder [Upper_Intermediate_ch]	-0.022	-0.059 – 0.014	0.230
GroupOrder [Upper_Intermediate_en]	-0.010	-0.048 – 0.029	0.620
GroupOrder [Advanced_ch] *poly(Scaled_Word_Story_Order,2)1	-0.086	-0.725 – 0.554	0.793
GroupOrder [Advanced_en]* poly(Scaled_Word_Story_Order,2)1	-0.142	-0.716 – 0.432	0.628
GroupOrder [Upper_Intermediate_ch]*poly(Scaled_Word_Story_Order,2)1	-0.774	-1.312 – -0.236	**0.005**
GroupOrder [Upper_Intermediate_en]*poly(Scaled_Word_Story_Order,2)1	-0.518	-1.120 – 0.083	0.091
GroupOrder [Advanced_ch] *poly(Scaled_Word_Story_Order,2)2	0.420	-0.378 – 1.218	0.302
GroupOrder [Advanced_en] *poly(Scaled_Word_Story_Order,2)2	-0.712	-1.459 – 0.035	0.062
GroupOrder [Upper_Intermediate_ch]*poly(Scaled_Word_Story_Order,2)2	-0.421	-1.149 – 0.306	0.257
GroupOrder [Upper_Intermediate_en]*poly(Scaled_Word_Story_Order,2)2	-0.393	-1.166 – 0.380	0.319
GroupOrder [Advanced_ch] * Log_Freq_N	-0.010	-0.015 – -0.005	**<0.001**
GroupOrder [Advanced_en] * Log_Freq_N	-0.001	-0.006 – 0.004	0.809
GroupOrder [Upper_Intermediate_ch] *Log_Freq_N	-0.007	-0.012 – -0.002	**0.003**
GroupOrder [Upper_Intermediate_en] *Log_Freq_N	-0.003	-0.008 – 0.002	0.218
GroupOrder [Advanced_ch] * Wordlength_Next	-0.002	-0.006 – 0.003	0.445
GroupOrder [Advanced_en] * Wordlength_Next	-0.007	-0.010 – -0.003	**0.001**
GroupOrder [Upper_Intermediate_ch*Wordlength_Next	-0.004	-0.008 – -0.001	**0.021**
GroupOrder [Upper_Intermediate_en]*Wordlength_Next	-0.001	-0.005 – 0.003	0.715
GroupOrder [Advanced_ch]* poly(Log_Freq_Prev, 3)1	-0.435	-1.092 – 0.222	0.194
GroupOrder [Advanced_en]* poly(Log_Freq_Prev, 3)1	-0.132	-0.730 – 0.467	0.666
GroupOrder [Upper_Intermediate_ch]*poly(Log_Freq_Prev, 3)1	-0.895	-1.470 – -0.320	**0.002**
GroupOrder [Upper_Intermediate_en]*poly(Log_Freq_Prev, 3)1	-0.083	-0.721 – 0.555	0.799
GroupOrder [Advanced_ch] * poly(Log_Freq_Prev, 3)2	-0.524	-1.173 – 0.124	0.113
GroupOrder [Advanced_en]	-0.774	-1.368 – -0.180	**0.011**

* poly(Log_Freq _Prev, 3)2			
GroupOrder [Upper_Intermediate _ch]*poly(Log _Freq_Prev, 3)2	-0.886	-1.458 – -0.314	**0.002**
GroupOrder [Upper_Intermediate _en]*poly(Log _Freq_Prev, 3)2	-1.160	-1.787 – -0.533	**<0.001**
GroupOrder [Advanced_ch] * poly(Log_Freq _Prev, 3)3	-0.817	-1.468 – -0.166	**0.014**
GroupOrder [Advanced_en] * poly(Log_Freq _Prev, 3)3	-0.473	-1.067 – 0.121	0.118
GroupOrder [Upper_Intermediate _ch]*poly(Log _Freq_Prev, 3)3	-0.351	-0.923 – 0.222	0.230
GroupOrder [Upper_Intermediate _en]*poly(Log _Freq_Prev, 3)3	-0.563	-1.187 – 0.061	0.077

Appendix 9 Chinese Reading Study
Effect of Variables on Gaze Duration

Predictors	*Estimates*	*CI*	*p*
(Intercept)	1.509	1.500 – 1.518	**<0.001**
GroupOrder [Advanced_en]	-0.001	-0.012 – 0.011	0.917
GroupOrder [Upper_Intermediate_ch]	-0.008	-0.020 – 0.004	0.181
GroupOrder [Upper_Intermediate_en]	-0.004	-0.016 – 0.009	0.554
GroupOrder [Advanced_ch] * Scaled_Word _Story_Order	-0.001	-0.002 – 0.000	0.065
GroupOrder [Advanced_en] * Scaled_Word _Story_Order	-0.000	-0.002 – 0.001	0.493
GroupOrder [Upper_Intermediate_ch]*Scaled_Word _Story_Order	-0.002	-0.003 – -0.001	**0.001**
GroupOrder [Upper_Intermediate_en]*Scaled_Word _Story_Order	-0.001	-0.002 – 0.001	0.329
GroupOrder [Advanced_ch] * Log_Freq_N	-0.005	-0.007 – -0.003	**<0.001**
GroupOrder [Advanced_en] * Log_Freq_N	-0.002	-0.003 – -0.000	**0.012**
GroupOrder [Upper_Intermediate_ch]*Log_Freq_N	-0.003	-0.005 – -0.002	**<0.001**
GroupOrder [Upper_Intermediate_en]*Log_Freq_N	-0.002	-0.004 – -0.001	**0.004**
GroupOrder [Advanced_ch] * Wordlength_Next	-0.001	-0.003 – 0.000	0.122
GroupOrder [Advanced_en] * Wordlength_Next	-0.003	-0.004 – -0.001	**<0.001**
GroupOrder [Upper_Intermediate_ch]*Wordlength_Next	-0.002	-0.003 – -0.001	**0.002**
GroupOrder [Upper_Intermediate_en]*Wordlength_Next	-0.001	-0.002 – 0.000	0.176
GroupOrder [Advanced_ch] * poly(Log_Freq _Prev, 3)1	-0.112	-0.314 – 0.090	0.276
GroupOrder [Advanced_en] * poly(Log_Freq _Prev, 3)1	-0.088	-0.272 – 0.096	0.351
GroupOrder [Upper_Intermediate_ch]*poly(Log_Freq_Prev, 3)1	-0.232	-0.409 – -0.055	**0.010**
GroupOrder [Upper_Intermediate_en]*poly(Log_Freq_Prev, 3)1	-0.006	-0.202 – 0.190	0.954
GroupOrder [Advanced_ch] * poly(Log_Freq _Prev, 3)2	-0.203	-0.403 – -0.004	**0.046**
GroupOrder [Advanced_en] * poly(Log_Freq _Prev, 3)2	-0.264	-0.447 – -0.081	**0.005**
GroupOrder [Upper_Intermediate_ch]*poly(Log_Freq_Prev, 3)2	-0.289	-0.465 – -0.113	**0.001**
GroupOrder [Upper_Intermediate_en]*poly(Log_Freq_Prev, 3)2	-0.412	-0.604 – -0.219	**<0.001**
GroupOrder [Advanced_ch] * poly(Log_Freq _Prev, 3)3	-0.267	-0.467 – -0.068	**0.009**

GroupOrder [Advanced_en] * poly(Log_Freq _Prev, 3)3	-0.133	-0.315 – 0.049	0.152
GroupOrder [Upper_Intermediate_ch]*poly(Log_Freq_Prev, 3)3	-0.105	-0.281 – 0.071	0.244
GroupOrder [Upper_Intermediate_en]*poly(Log_Freq_Prev, 3)3	-0.176	-0.368 – 0.015	0.071
GroupOrder [Advanced_ch] * Log_Freq_Next	-0.001	-0.002 – 0.001	0.258
GroupOrder [Advanced_en] * Log_Freq_Next	-0.002	-0.003 – -0.000	**0.019**
GroupOrder [Upper_Intermediate_ch]*Log_Freq_Next	-0.002	-0.003 – -0.000	**0.026**
GroupOrder [Upper_Intermediate_en]*Log_Freq_Next	-0.001	-0.003 – 0.000	0.082

Appendix 10 Chinese Reading Study
Effect of Variables on Total Reading Time

Predictors	*Estimates*	*CI*	*p*
(Intercept)	5.415	5.315 – 5.514	**<0.001**
GroupOrder [Advanced_en]	-0.015	-0.144 – 0.114	0.822
GroupOrder [Upper_Intermediate _ch]	-0.083	-0.213 – 0.046	0.207
GroupOrder [Upper_Intermediate _en]	-0.041	-0.176 – 0.095	0.556
GroupOrder [Advanced_ch] * Scaled_Word _Story_Order	-0.013	-0.026 – -0.000	**0.043**
GroupOrder [Advanced_en] * Scaled_Word _Story_Order	0.002	-0.009 – 0.014	0.691
GroupOrder [Upper_Intermediate _ch]*Scaled_Word _Story_Order	-0.028	-0.039 – -0.017	**<0.001**
GroupOrder [Upper_Intermediate _en]*Scaled_Word _Story_Order	0.001	-0.011 – 0.013	0.914
GroupOrder [Advanced_ch] * Wordlength_N	0.037	0.016 – 0.058	**0.001**
GroupOrder [Advanced_en] * Wordlength_N	0.023	0.004 – 0.043	**0.018**
GroupOrder [Upper_Intermediate _ch]*Wordlength_N	0.028	0.009 – 0.047	**0.003**
GroupOrder [Upper_Intermediate _en]*Wordlength_N	0.018	-0.002 – 0.038	0.078
GroupOrder [Advanced_ch] * Log_Freq_N	-0.045	-0.067 – -0.022	**<0.001**
GroupOrder [Advanced_en] * Log_Freq_N	-0.017	-0.038 – 0.004	0.107
GroupOrder [Upper_Intermediate _ch]*Log_Freq_N	-0.032	-0.053 – -0.012	**0.002**
GroupOrder [Upper_Intermediate _en]*Log_Freq_N	-0.027	-0.048 – -0.005	**0.016**
GroupOrder [Advanced_ch] * Wordlength_Next	-0.018	-0.034 – -0.002	**0.026**
GroupOrder [Advanced_en] * Wordlength_Next	-0.025	-0.039 – -0.011	**<0.001**
GroupOrder [Upper_Intermediate _ch]*Wordlength_N ext	-0.019	-0.033 – -0.006	**0.006**
GroupOrder [Upper_Intermediate _en]*Wordlength_N ext	-0.006	-0.021 – 0.009	0.411
GroupOrder [Advanced_ch] * poly(Log_Freq _Prev, 3)1	-1.825	-3.922 – 0.272	0.088
GroupOrder [Advanced_en] * poly(Log_Freq _Prev, 3)1	-0.344	-2.254 – 1.566	0.724
GroupOrder [Upper_Intermediate _ch]*poly(Log_Freq _Prev, 3)1	-1.850	-3.687 – -0.012	**0.049**
GroupOrder [Upper_Intermediate _en]*poly(Log_Freq _Prev, 3)1	-0.278	-2.308 – 1.752	0.788
GroupOrder [Advanced_ch] * poly(Log_Freq	-4.062	-6.113 – -2.010	**<0.001**

_Prev, 3)2			
GroupOrder [Advanced_en] * poly(Log_Freq _Prev, 3)2	-3.448	-5.331 – -1.565	**<0.001**
GroupOrder [Upper_Intermediate _ch]*poly(Log_Freq _Prev, 3)2	-3.645	-5.458 – -1.832	**<0.001**
GroupOrder [Upper_Intermediate _en]*poly(Log_Freq _Prev, 3)2	-4.519	-6.505 – -2.533	**<0.001**
GroupOrder [Advanced_ch] * poly(Log_Freq _Prev, 3)3	-2.175	-4.233 – -0.116	**0.038**
GroupOrder [Advanced_en] * poly(Log_Freq _Prev, 3)3	-1.870	-3.748 – 0.009	0.051
GroupOrder [Upper_Intermediate _ch]*poly(Log_Freq _Prev, 3)3	-3.190	-5.007 – -1.374	**0.001**
GroupOrder [Upper_Intermediate _en]*poly(Log_Freq _Prev, 3)3	-2.020	-3.994 – -0.047	**0.045**
GroupOrder [Advanced_ch] * Log_Freq_Next	-0.007	-0.023 – 0.008	0.350
GroupOrder [Advanced_en] * Log_Freq_Next	-0.013	-0.027 – 0.001	0.079
GroupOrder [Upper_Intermediate _ch]*Log_Freq_Nex t	-0.018	-0.032 – -0.004	**0.011**
GroupOrder [Upper_Intermediate _en]*Log_Freq_Nex t	-0.011	-0.026 – 0.004	0.137

Appendix 12A English Reading Study
Effect of Variables on Landing Position

Predictors	*Estimates*	*CI*	*p*
(Intercept)	2.992	2.007 – 3.978	**<0.001**
GroupOrder [Advanced_ch]	1.005	-0.923 – 2.933	0.307
GroupOrder [Advanced_en]	4.378	2.688 – 6.069	**<0.001**
GroupOrder [Upper_Intermediate_ch]	3.567	1.877 – 5.256	**<0.001**
GroupOrder [Upper_Intermediate_en]	2.818	0.990 – 4.645	**0.003**
GroupOrder [Native]*poly (Wordlength_N, 2)1	-36.387	-198.911 – 126.138	0.661
GroupOrder [Advanced_ch] *poly(Wordlength_N, 2)1	1555.907	1351.037 – 1760.777	**<0.001**
GroupOrder [Advanced_en] *poly(Wordlength_N, 2)1	2201.307	2015.450 – 2387.164	**<0.001**
GroupOrder [Upper_Intermediate_ch]*poly (Wordlength_N, 2)1	1940.225	1754.597 – 2125.854	**<0.001**
GroupOrder [Upper_Intermediate_en]*poly(Wordlength_N, 2)1	2094.767	1900.618 – 2288.915	**<0.001**
GroupOrder [Native]*poly (Wordlength_N, 2)2	-61.099	-217.310 – 95.111	0.443
GroupOrder [Advanced_ch] *poly(Wordlength_N, 2)2	524.420	325.133 – 723.708	**<0.001**
GroupOrder [Advanced_en] *poly(Wordlength_N, 2)2	415.870	235.357 – 596.383	**<0.001**
GroupOrder [Upper_Intermediate_ch]*poly (Wordlength_N, 2)2	487.805	307.268 – 668.341	**<0.001**
GroupOrder [Upper_Intermediate_en]*poly (Wordlength_N, 2)2	519.710	329.472 – 709.949	**<0.001**
GroupOrder [Native]*poly (Wordlength_Prev, 2)1	70.426	-26.461 – 167.314	0.154
GroupOrder [Advanced_ch] *poly(Wordlength_Prev,2)1	-677.934	-834.499 – -521.369	**<0.001**
GroupOrder [Advanced_en] *poly(Wordlength_Prev,2)1	-629.891	-759.259 – -500.523	**<0.001**
GroupOrder [Upper_Intermediate_ch]*poly (Wordlength_Prev, 2)1	-679.732	-808.650 – -550.815	**<0.001**
GroupOrder [Upper_Intermediate_en]*poly (Wordlength_Prev, 2)1	-832.325	-971.167 – -693.482	**<0.001**
GroupOrder [Native]*poly (Wordlength_Prev, 2)2	20.993	-74.703 – 116.688	0.667
GroupOrder [Advanced_ch] *poly(Wordlength_Prev,2)2	132.942	-21.447 – 287.331	0.091
GroupOrder [Advanced_en]	198.360	69.498 – 327.222	**0.003**

*poly(Wordlength_P rev,2)2			
GroupOrder [Upper_Intermediate _ch]*poly (Wordlength_Prev, 2)2	282.72 2	155.493 – 409.952	**<0.001**
GroupOrder [Upper_Intermediate _en] * poly(Wordlength_Pr ev, 2)2	299.81 8	161.727 – 437.909	**<0.001**
GroupOrder [Native]*poly (Wordlength_Next, 2)1	-77.43 7	-172.618 – 17.743	0.111
GroupOrder [Advanced_ch] *poly(Wordlength_N ext,2)1	381.49 8	225.564 – 537.431	**<0.001**
GroupOrder [Advanced_en] *poly(Wordlength_N ext,2)1	243.55 4	113.701 – 373.407	**<0.001**
GroupOrder [Upper_Intermediate _ch]*poly (Wordlength_Next, 2)1	248.82 7	120.476 – 377.179	**<0.001**
GroupOrder [Upper_Intermediate]*poly	249.04 2	110.849 – 387.235	**<0.001**
(Wordlength_Next, 2)1			
GroupOrder [Native] * poly(Wordlength_Ne xt, 2)2	- 124.07 5	-218.348 – -29.802	**0.010**
GroupOrder [Advanced_ch] *poly(Wordlength_N ext,2)2	-23.973	-177.883 – 129.936	0.760
GroupOrder [Advanced_en] *poly(Wordlength_N ext,2)2	- 120.15 7	-248.051 – 7.736	0.066
GroupOrder [Upper_Intermediate _ch]*poly (Wordlength_Next, 2)2	-11.902	-138.012 – 114.208	0.853
GroupOrder [Upper_Intermediate _en]*poly (Wordlength_Next, 2)2	-61.69 9	-197.571 – 74.173	0.373

Appendix 12B Chinese Reading Study
Effect of Variables on Landing Position

Predictors	*Estimates*	*CI*	*p*
(Intercept)	0.014	-0.067 – 0.095	0.741
GroupOrder [Advanced_en]	0.051	-0.037 – 0.138	0.260
GroupOrder [Upper_Intermediate _ch]	-0.044	-0.131 – 0.043	0.322
GroupOrder [Upper_Intermediate _en]	-0.023	-0.114 – 0.067	0.613
GroupOrder [Advanced_ch] *poly(Wordlength_N ext,2)1	-9.931	-15.241 – -4.621	**<0.001**
GroupOrder [Advanced_en] *poly(Wordlength_N ext,2)1	-4.976	-10.412 – 0.460	0.073
GroupOrder [Upper_Intermediate _ch]*poly (Wordlength_Next, 2)1	-3.868	-8.652 – 0.917	0.113
GroupOrder [Upper_Intermediate _en]*poly (Wordlength_Next, 2)1	-3.296	-8.542 – 1.949	0.218
GroupOrder [Advanced_ch] * poly(Wordlength _Next,2)2	4.165	-0.606 – 8.935	0.087
GroupOrder [Advanced_en] *poly(Wordlength_N ext,2)2	0.653	-4.272 – 5.578	0.795
GroupOrder [Upper_Intermediate _ch]*poly (Wordlength_Next, 2)2	4.684	0.385 – 8.983	**0.033**
GroupOrder [Upper_Intermediate _en]*poly (Wordlength_Next, 2)2	1.834	-2.867 – 6.535	0.444
GroupOrder [Advanced_ch] *poly(Fre_log_Prev, 2)1	-1.022	-5.142 – 3.099	0.627
GroupOrder [Advanced_en] *poly(Fre_log_Prev, 2)1	0.732	-3.483 – 4.947	0.734
GroupOrder [Upper_Intermediate _ch]*poly(Fre_log_P rev, 2)1	-2.254	-6.046 – 1.537	0.244
GroupOrder [Upper_Intermediate _en]*poly(Fre_log_P rev, 2)1	-1.572	-5.711 – 2.566	0.457
GroupOrder [Advanced_ch] *poly(Fre_log_Prev, 2)2	2.790	-1.238 – 6.818	0.175
GroupOrder [Advanced_en] *poly(Fre_log_Prev, 2)2	6.559	2.455 – 10.662	**0.002**
GroupOrder [Upper_Intermediate _ch]*poly (Fre_log_Prev, 2)2	3.546	-0.219 – 7.312	0.065
GroupOrder [Upper_Intermediate _en]*poly (Fre_log_Prev, 2)2	1.443	-2.667 – 5.554	0.491
GroupOrder [Advanced_ch] *poly(Fre_log_Next , 3)1	-2.841	-8.576 – 2.895	0.332
GroupOrder [Advanced_en] *poly(Fre_log_Next, 3)1	-1.926	-7.856 – 4.005	0.525

GroupOrder [Upper_Intermediate _ch]*poly (Fre_log_Next, 3)1	-2.894	-8.133 – 2.345	0.279
GroupOrder [Upper_Intermediate _en]*poly (Fre_log_Next, 3)1	-2.061	-7.839 – 3.716	0.484
GroupOrder [Advanced_ch] *poly(Fre_log_Next, 3)2	-1.608	-5.814 – 2.598	0.454
GroupOrder [Advanced_en] *poly(Fre_log_Next, 3)2	4.185	-0.132 – 8.501	0.057
GroupOrder [Upper_Intermediate _ch]*poly (Fre_log_Next, 3)2	3.519	-0.373 – 7.412	0.076
GroupOrder [Upper_Intermediate _en]*poly (Fre_log_Next, 3)2	-0.989	-5.231 – 3.253	0.648
GroupOrder [Advanced_ch] *poly(Fre_log_Next, 3)3	-5.529	-9.678 – -1.381	**0.009**
GroupOrder [Advanced_en] *poly(Fre_log_Next, 3)3	-1.767	-6.103 – 2.568	0.424
GroupOrder [Upper_Intermediate _ch]*poly (Fre_log_Next, 3)3	-1.845	-5.726 – 2.037	0.352
GroupOrder [Upper_Intermediate _en]*poly (Fre_log_Next, 3)3	-3.947	-8.136 – 0.242	0.065