The Visual Perception of Chinese Orthography: from Characters to Sentences

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Abstract

There are different aims in this thesis. The primary aim is to investigate visual perception in Chinese orthography, from its fundamentally distinct unit, characters, to sentence reading. The first aim of the thesis is to investigate how a single Chinese character is processed in many ways. We have looked into an effect called *orthographic satiation/decomposition* (Cheng & Wu, 1994). It refers to the feeling of uncertainty about the composition of some characters when staring at a character for too long. Lee (2007) extended Cheng and Wu's study (1996), and the results have showed that orthographic satiation occurred faster in females than males. We replicated Lee's study (Experiment 1) (Chapter 3), and have found that: (1) there was no significant difference between male and female and (2) a radical that can stand alone as a single character makes characters in which it occurs resistant to satiation.

Following orthographic satiation, in Chapter 4, we explored the preference for eye/hemisphere visual pathways in Chinese characters (Experiment 2 & 3) and words (Experiment 4). In English, researchers have reported a contralateral preference when four-letter words were presented very quickly using a haploscope (Obregón & Shillcock, 2012) . It raises the question of whether presenting Chinese characters and words will show similar results considering the complexity and the special characteristics of Chinese orthography. We presented Chinese characters and words to participants using a haploscope. Our results showed that: (1) the contralateral visual pathway was preferred in perceiving right-left structured Chinese characters and two-character words, (2) when a semantic radical is projected to the LH, participants are able to recognise the semantic component better, (3) neighbourhood size (NS) (Tsai, Lee, Lin, Tzeng & Hung, 2006) affects how participants recognise words, and(4) males do better than females recognising characters but not words.

After investigating the recognition of Chinese characters and words, we analysed the eye-movements in Chinese and English reading corpora. The processes of reading are intuitively thought to be more complex than perceiving a single character or words. The last studies in the thesis focused on the reading behaviours in Chinese and English. The eye movement differences and similarities between reading Chinese and English were investigated.

In Chapter 5, we showed that reading Chinese elicits more divergence of the eyes within a fixation, compared with reading English. We interpreted these data in terms of recent demonstrations that apparent size causes increases in visual sensitivity (Arnold & Schindel, 2010) and engages more cortical resource in V1 (Kersten & Murray, 2010). Our analyses were based on movement within exactly temporally synchronized binocular fixations in the reading of Chinese and English 5000-word multi-line texts, using monocular calibration, with EyeLink-2 technology. When faced with visually complex orthography, the oculomotor system 'tricks' the rest of the visual system into 'zooming in' on the text. We consolidated the relevant theorizing into the 'Divergence Affects Reading' (DOLLAR) Theory.

In Chapter 6, we reported that (1) vertical movements within a fixation tend to be smaller than horizontal ones, and (2) vertical movements within a fixation tend to be upwards. We speculated that it is appropriate for the earlier part of the fixation to be associated with visual recognition and for the later part of the fixation to be associated with executive action. The tendency to move upwards also suggested that in real-world reading, the upper part of words/characters were informative.

In the last chapter analysing the reading corpus (Chapter 7), we reported corrective saccades after return sweeps. We found that in English, there were more corrective saccades after return sweeps than in Chinese. We interpreted these data in terms of spatial coding (Kennedy & Murray, 1987). In terms of

Chinese and English differences, the stimuli that were used in our corpus show that the length for each line was different in English. The length for each line in Chinese was less different. Though the first character of each line was at the same place for two languages, it was more difficult for English subjects to locate the correct place after return sweeps because the length of return sweeps was different.

In short, this thesis investigated visual perception in Chinese orthography, in terms of characters, words, and real-world reading. Moreover, we compared the differences and similarities between languages (English and Chinese). Despite the fact that the orthographies of English and Chinese are very different, we still found similar effects (e.g., contralateral preference) between them. This thesis thus has contributed to a better understanding of the differences and similarities between English and Chinese in terms of the orthographies.

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Declaration

I declare that this thesis was composed by myself, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted for any other degree or professional qualification except as specified. Some of the material used in this thesis has been published in the following paper:

1. Hsiao, Y., Shillcock, R., Obregón, M., Kreiner, H., Roberts, M.A.J, & McDonald, S. (2017). Differential vergence movements in reading Chinese and English: Greater fixation-initial binocular disparity is advantageous in reading the denser orthography. Quarterly Journal of Experimental Psychology, DOI: 10.1080/17470218.2017.1350866.

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Chapter 1

Introduction

The behavior of reading seems so natural that people do not have to think how to convert symbols into meanings. Among all writing language systems, the written system in Chinese is one of the logographic systems. Different from alphabetical writing system, such as English, a simple Chinese character means a certain thing. For example, "刀" means knives, and when a stroke is put on the knife, it becomes "刃", which means blade. The character "刀" (knives) is evolved from the actual shape of a knife if we trace back to the Oracle bone script era[1]. The Chinese character itself, can, therefore, be ideographic.

Being distinct from alphabetical writing systems, will the behavior of reading and perceiving Chinese orthography differ from English orthography? In a preschool children longitudinal study (Ho & Bryant, 1999), the visual precursors of learning reading in Chinese and English were investigated. English children seemed to perform better in shape constancy than Chinese children; meanwhile, Chinese children performed better in spatial relationships, position in space and figure-ground. The finding suggested that different visual

[1]In Shang Dynasty, emperors divined by drilling and inscribing turtle shells and ox scapulae before any important events. The diviner heated the shells and the shells cracked, appearing like "I-" or "-I", which evolved into 卜, meaning to divine in modern Chinese character. The cracks were then interpreted to answer the emperors' questions. About 1000 out of 4500 Shang signs evolved into modern Chinese characters (Robinson, 2007).

skills play different roles in reading English and Chinese. Some neuroimaging studies (e.g., Tan, Laird, Li, & Fox, 2005) show that the left posterior superior temporal cortex is activated in only English reading, whereas the left middle/ inferior frontal cortex is more activated in Chinese than English reading[2]. We can see an obvious difference in Chinese and English reading regarding linguistic and visual processing. Though there are studies of reading Chinese characters, the studies are still far fewer than studies of reading English words. Therefore, in this thesis, we investigate the visual perception of Chinese orthography, starting with the smallest Chinese orthography unit, Chinese characters.

1.1 Chinese Orthography

As the smallest unit in Chinese orthography, characters are also regarded as the perceptual unit of orthography (Hoosain, 1991). In alphabetic orthography, words vary in length or the number of component letters. Chinese characters are constituted by numbers of strokes. With a few strokes, different stroke patterns, which are recurrent units of Chinese orthography, are comprised. Most characters are composed of at least two stroke patterns. Characters that cannot be decomposed or are integral are regarded as single bodies (Chen, Allport, & Marshall, 1996; Hsiao & Shillcock, 2006).

The Chinese term Bu Shou refers to a specific subgroup of single bodies that are listed in Chinese dictionaries as the index. There are 214 Bu Shou in a traditional Chinese dictionary (Mandarin Promotion Council, Ministry of Education, Taiwan, 2000). A single body listed in Bu Shou has been further termed a lexical radical (Chen et al., 1996), and it occurs in a regulated position in char-

[2]Left posterior superior temporal cortex was found to be involved in phonological access generally (Burton, LoCasto, Krebs-Noble, & Gullapalli, 2005); meanwhile, left inferior frontal cortex was involved in semantics (Demb et al., 1995).

acters. *semantic radicals* referred to lexical radicals with semantic functions, and each character contains exactly one semantic radical. Any remaining part of a character usually indicates the pronunciation of the character, which is referred to as a *phonetic radical*. In other words, a character is usually composed of two radicals, which can also be referred as bodies. The semantic radical is called Bu Shou. The radicals are composed of strokes (see Figure 1.1).

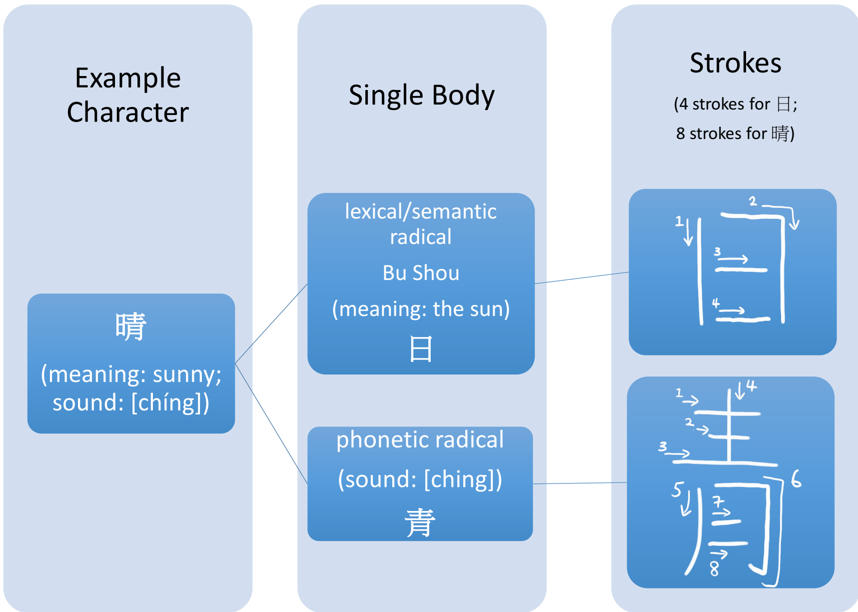

Figure 1.1: Example of the relationship between characters, bodies, and strokes

1.1.1 Classification of Chinese Characters

There are four main types of Chinese characters: *pictographs*, *indicatives*, *ideographs*, and *semantic-phonetic compounds*. Pictographs depict concrete objects, such as "日"(sun) and "山" (mountain). Less than 1 % of characters are comprised of pictographs (DeFrancis, 1989). Indicatives are encoded as images (Wang, 1973). With a sign or indication, an indicative can indicate an abstract characteristic, such as “上” (up) which derived from a dot pointed above the horizon, or it can also indicate a concrete characteristic, such as “本” (root) that derived from a dot pointed on the bottom of the tree (木). Pictographs and indicatives can be regarded as simple characters.

Ideographs and semantic-phonetic compounds are compound characters with two or more radicals containing new meanings. The ideograph “酒” (wine), for instance, consists of the radical 水 (also written as “氵”: water or liquids) and 酉 (the bottle for wine), portraying the liquid in the bottle for wine. The last and most common type of character that shares 81% of 7000 frequent characters in a Chinese dictionary are semantic-phonetic compounds (Li & Kang, 1993). A semantic-phonetic compound consists of a semantic and a phonetic radical, with the most commonly seen left-right structure (e.g., [ma]: mother; semantic radical: 女 [female]; phonetic radical: [mǎ][3]). But still, an up-down semantic-phonetic compound can also be seen (e.g., 爸 [bà]: dad; semantic radical: 父 [father]; phonetic radical: 巴 [ba]).

1.1.2 Regularity, Consistency, and Structure of Phonetic Compounds

A phonetic radical and a semantic radical constitute a phonetic compound. The semantic radical provides the meaning of the phonetic compound, while the phonetic radical gives partial information of pronunciation of the phonetic compound. The regularity of pronunciation between the phonetic radical and the phonetic compound can be categorised into three groups—regular characters, semi-regular characters, and irregular characters. For example, the regular character “趾” (toe) is pronounced “zhi”. The semantic radical on the left “足” means the foot. The phonetic radical on the right “止” is pronounced “zhi”, which is pronounced identically with its compound “趾”. The semi-

[3]The pronunciation marks of Chinese characters in this thesis will be Pinyin, which is a spelling system for Chinese characters based on the Roman alphabet.

regular character "河" (river) is pronounced "hé". The meaning of the semantic radical on the left "氵" is water. The phonetic radical "可" is pronounced "ke". The irregular character "池" (pound) is pronounced "chí" with a semantic radical referring to water. The phonetic radical on the right "也" is pronounced "ye". Among irregular characters, some of them shared the same onset (alliteration) or rhyme (rhyming) (*cf.* Hsiao & Shillcock, 2006).

Consistency of phonetic compounds also provides another feature to categorise phonetic compounds. A phonetic radical that appears in a character in different positions will be treated differently in terms of consistency (Taft & Zhu, 1999). Therefore, if a given phonetic compound shares the phonetic radical with the other characters in the same position and pronounced identically, the phonetic compound is considered as consistent with the other characters (Fang, Horng, & Tzeng, 1986).

Regularity and frequency effects were found in processing Chinese phonetic compounds in a naming task. Regular characters were named faster than irregular characters. An interaction of frequency by regularity was found in Chinese as it was found in English. The frequency effect was only obtained in low-frequency characters (e.g., Hue, 1992; Liu, Wu, & Chou, 1996). Consistency and frequency effects were also reported in the processing of phonetic compounds. It was found that in both high- and low-frequency conditions, consistent characters were named faster than inconsistent characters (e.g., Hue, 1992).

Most phonetic compounds are comprised of a semantic radical (S) on the left and a phonetic radical (P) on the right (e.g., 詳 [xiáng]: details; S: 言 [words]; P: 羊 [yáng]). A minority of phonetic compounds are PS characters, with a phonetic radical on the left and a semantic radical on the right (eg., 翔 [xiáng]: fly; P: 羊 [yáng]; S: 羽 [feather]) (Feldman & Siok, 1999; see also Hsiao & Shillcock, 2006). Up to 81% of Chinese characters are composed of one semantic radical and one phonetic radical among 7000 frequent characters in Chinese orthography (Li & Kang, 1993); therefore, in part of this current thesis, we investigate Chinese characters using SP-PS compounds to explore the property of visual perception in Chinese characters.

1.1.3 Chinese Words and Reading

However, with time, the numbers of Chinese characters became insufficient. To give definitions of new concepts and things, compounds of characters were created. Therefore, Chinese words could be either composed of one or more than one (rarely longer than four) characters. Among all the Chinese words in a particular Chinese corpus (Academia Sinica, 1998), only about 9% of words consisted of a single character while 76% were composed of two or three characters (Tsai & McConkie, 2003). In the modern Chinese writing system, there are two main sets: the traditional font and the simplified font. The simplified font is used mainly in China, which reduced the visual complexity of many characters in the 1950s, and the traditional font is used in Taiwan and Hong Kong (Table 1.1).

Font	Example
Traditional	我是臺灣人，臺灣是個美麗的國家。
Simplified	我是台湾人，台湾是个美丽的国家。

Table 1.1: Example of traditional Chinese and simplified Chinese font, meaning: I am Taiwanese, and Taiwan is a beautiful country.

As shown in Table 1.1, Chinese script consists of a series of square-shaped characters with different visual complexity that has the same horizontal extent. The main reading difference between alphabetic and Chinese scripts is the space. When reading Chinese written text, punctuation is the only clue about where to stop or to end. Therefore, there are no explicit boundaries in Chinese apart from punctuation.

1.2 Human Visual Perception in Cognitive Views

Research on human visual perception could be categorized into different fields, many of which look into the issue through psychophysical and cognitive perspectives (e.g., Levelt, 1968; Martinez-Conde, Macknik, & Hubel, 2004). In this thesis, we have investigated Chinese orthography from its basic form, characters, to words, and finally to sentences. Two different visual effects, retinal stabilization and foveal splitting, will be brought into our discussion.

A very early study about the loss of gestalt in English investigated the feeling of changes of words when native English speakers were asked to stare at an English word for a long time (Severance & Washburn, 1907). Pritchard, Heron, and Hebb (1960) reported that when images or words were stabilized on the retina, the images or words would disappear and reappear repeatedly.

The issue of how the human fovea is projecting to both hemispheres has long been debated. It can be understandable that people regard the human fovea as a single concentration of receptors that directly projects to both hemispheres simultaneously. However, some evidence and computational and neuropsychological theories suggest that the fovea is split vertically into two halves (Brysbaert, 1994; Lavidor & Walsh, 2004; Luo, Shan, Zhu, Weng, & He, 2011; McDonald & Shillcock, 2005; Shillcock, Roberts, Kreiner, & Obregón, 2010), and the effect is called foveal splitting.

1.2.1 Fading Effects and Retinal Stabilization

In the early 20th century, Severance and Washburn (1907) reported an effect that occurred when people stared at an English word for too long, they would concentrate on a part of the word and some letters would change shape (e.g., "e" became "c"). The loss of associations with the words indicates a similarity with orthographic satiation; therefore, we believe that the loss of perceptual coherence after prolonged viewing occurs in both reading English and Chinese. In the real world, the movement of the eyeball occurs either voluntarily or involuntarily. Voluntary eye movements, involving looking at a picture and reading, are much bigger than involuntary eye movements that make images drift away from the centre of the fovea slowly. Ditchburn and Fender (1955) managed to prevent the drifting and made the images stabilized on the retina. They, therefore, found that the images that stabilized on the retina would fade and disappear, and then, after a while, the images regenerated and reappeared as whole or as fragments for the subject.

Studies in stabilized images reported that when images were stabilized on the retina, the images fragmented into organized entities with reduced visual complexity before fading (Pritchard, 1961; Pritchard, Heron, & Hebb, 1960). This fading effect not only occurs in images but also in linguistic stimuli. Pritchard (1961) found that when a word was stabilized, such as BEER, the word was perceived as PEER, PEEP, BEE and finally BE before it faded away. Pritchard (1961) explained that the occurrence of fading images during stabilization was because innate mental laws determined perception so that a pattern was perceived as a global construct together with all its elements. Furthermore, Inhoff and Topolski (1994) suggested that the perceived pattern of fragmentation during retinal stabilization was determined by the availability of structured and meaningful memory representations. Inhoff and Topolski (1994) brought out the representational-decay hypothesis and investigated the effects of retinal stabilization on the perception of words to explore whether morphemic knowledge constrained fragmentation. The results demonstrated a progressive periphery-to-centre loss of visibility, in which the fading occurred from either beginning or ending letters to centre letters.

Topolski and Inhoff (1995) further investigated retinal stabilization based on Pritchard's (1961) chimeric stimuli, which, according to Pritchard, fragmented into less complex meaningful images. Topolski and Inhoff, therefore, suggested letter-level knowledge. Instead of using English words, they used 26 upper- and lower- cases letters. The findings were not exactly coherent with Pritchard's results, in which complex forms turned into simpler forms, and simple forms faded away as intact units. On the contrary, while half of Topolski and Inhoff's trials faded as predicted in Pritchard's study, other complex forms, such as E, might turn into lines before fading. Thus, Topolski and Inhoff suggested that visual features were representational building blocks of letter representations.

When we are inspecting the world, fixation of gaze is required to see the details of the world. However, at the point of nearly perfect motionless fixation, the world would fade away caused by the adaptation of neurons (Martinez-Conde, Machnik, Troncoso,& Dyar, 2006). Microsaccades during fixation, in earlier studies were considered to be an essential part of normal vision (Ditchburn, Fender, & Mayne, 1959); on the other hand, some researchers believed that microsaccades were meaningless and useless (Steinman, Cunitz, Timberlake, & Herman, 1967). In some later studies (Martinez-Conde, Macknik, & Hubel, 2000; Martinez-Conde, Macknik, & Hubel 2002), microsaccades were further proved to be correlated with increases in neural firing in the visual pathway at all levels. These findings suggested that microsaccades play a potentially substantial role in fixation. Martinez-Conde et al. (2006) hypothesized that microsaccades may counteract Troxler fading (Troxler, 1804). Troxler fading refers to an effect when a person fixates at one point for certain time, the peripheral images will fade away. They further hypothesized that Troxler fading occurred because of the receptive field in the periphery being larger than the amplitudes of drifts and tremors. Martinez-Conde et al. (2006) tested their hypotheses by asking participants to indicate the occurrence of Troxler fading and the eye movements of the participants were recorded simultaneously.

The findings showed that before fading effect occurred, the probability and magnitude of microsaccades decreased. On the other hand, before transitions towards visibility, the rate and extent of microsaccades increased. These results demonstrated a close association between the suppression of microsaccades and fading and also further suggested a relationship between the production of microsaccades and target visibility during fixation. Troncoso, Macknik, and Martinez-Conde (2008) further examined whether microsaccades not only counteract low-level adaptation but play a part in higher perceptual processing. Therefore, instead of using Troxler fading, they used an artificial scotoma to observe the role of microsaccades during fixation and further found that microsaccades counteracted the perceptual filling-in of the artificial scotoma, thereby driving an additional visibility.

Through the discussion of the development of the research on retinal stabilization, we have seen what people experienced when words or images were more or less stabilized on the retina (e.g., Severance & Washburn, 1907; Ditchburn & Fender, 1955). We also understood the role of physical movements during retinal stabilization (Martinez-Conde et al., 2006). However, studies on retinal stabilization and fading effects were all carried out using English; therefore, we raised the question whether different writing systems (Chinese, in this case) would show different or similar results when the same technique is employed.

1.2.2 Foveal Splitting

The fact that the right visual hemifield is advantaged compared with the left hemifield in lexical process has long been established (Zaidel, Clarke, & Suyenobu, 1990). The fovea is split corresponding to the central line between the two hemispheres. Therefore, when a person is fixating at the center of an object, information that falls to the right of the fixation is projected to the left hemisphere, which typically dominates languages processing (Brysbaert, 1994; Melamed & Zaidel, 1993; Shillcock, Ellison & Monaghan, 2000).

The split fovea theory proposed that the representation of the fovea is split between the two hemispheres entirely, suggesting that the fovea is divided vertically along the centre of the fovea (Ellis & Brysbaert, 2010; Lavidor & Walsh, 2004; Luo, et al., 2011; Shillcock, et al., 2010; Shillcock, et al., 2000). Some imaging studies have showed evidence for split fovea theory (Portin, Vanni & Hari, 1999; Portin, Salenius, Salmelin, Hari, 1998). Portin et al. (1999) used magnetoencephalographic (MEG) to investigate brain activation when presenting visual stimuli at different eccentricities (0.5-6.0°) and they found strong responses in the contralateral occipital cortex. Behavioral studies (Harvey, 1978; Huan, 1978; Lines & Milner, 1983) also found evidence for split fovea theory.

However, the bilateral projection theory holds an entirely opposite view. The bilateral projection theory proposed that visual information sent to the fovea would overlap and be projected to both hemispheres extending up to 1 degree for either side of fixation from the foveal midline (Fendrich, Wessinger, & Gazzaniga, 1996; Gazzaniga, 2000). Anatomical studies (Bunt, & Minckler 1977; Stone, 1966) showed evidence for bilateral projection in some mammals foveal sparing did occur. When the visual pathway is damaged unilaterally, the visual field that close (2-3 degrees) to the fovea is spared. Nevertheless, for patients with hemianopia, not all of them showed foveal sparing. Celesia, Meredith, and Pluff (1983) found that about 36% of patients with hemianopia showed no foveal sparing; on the contrary, they showed foveal splitting.

In more recent studies, researchers in the computational field tried to model foveal splitting. For example, Hsiao, Shieh, and Cottrell (2008) explored split architecture using face and object recognition. The visual field split was modeled by Double Filtering by Frequency (DFF) (Ivry & Robertson, 1998), which claimed that when the brain was receiving information, two filtering stages occurred. The task-relevant frequency information was attentionally selected. At the second stage, the right hemisphere amplified the low-frequency information, and the left hemisphere biased the high-frequency information. Applying DFF, Hsiao et al. (2008) compared three cognitive architectures with different converged timings and investigated the cognitive plausibility of these three architectures to illustrate the left-side bias effect in face recognition as observed in human data. Their modeling of early convergence failed, suggesting that convergence occurred at the later stage.

Visual information received by each hemified is projected to the contralateral occipital lobe because neural fibers from the nasal hemiretinae in the optic chiasm and uncrossed fibers from the temporal hemiretinae are divided. The information is combined later through interhemispheric transfer. The interhemispheric transfer does not only play a role in binocular vision (Mitchell & Blakemore, 1970), but also in visual word recognition (Hunter, Brysbaert, & Knecht, 2007; Monaghan & Shillcock, 2008). Strother, Zhou, Coros, and Vilis (2017) investigated visual hemifield integration and cerebral lateralisation using fMRI, and found that left-lateralised neural mechanisms were responsible for normal reading.

In summary, the issue of foveal splitting has been controversial. However, by discussing the studies on foveal splitting, we have seen support for foveal splitting. Moreover, while the bilateral foveal projection theory could not explain foveal splitting (Leff, 2004), the foveal splitting theory could explain foveal sparing (Lavidor & Walsh, 2004). Leff (2004) argued that the entire representation represented in the cortex was unlikely to be destroyed by random lesioning because the fovea is extensive. Studies (e.g., Obregón & Shillcock, 2012) also showed an eye/hemisphere contralateral preference when projecting English words to native English speakers. Therefore, we were interested in how native Chinese speakers would behave when viewing Chinese characters projected so as to allow foveal splitting. In this thesis, we specifically investigate the eye/hemisphere contralateral preference as in Obregón and Shillcock's (2012) study.

1.3 Eye Movements in Reading

Studies on word recognition have shown that letters are the basic unit of word recognition (Pelli, Farell, & Moore, 2003). Pelli et al. (2003) presented parts of words to people, and found that people were unable to recognise the words unless the letters of the words were identifiable. In the past decades, research on eye movements has indicated that readers' eye movements could be influenced by a range of properties of words that being read (e.g., Rayner, 2009). Words have been regarded as the basic units for ongoing processing and saccade targeting in many of the dominant models of eye movements in contextual reading (e.g., Engbert, Nuthmann, Richter, & Kliegl, 2005; Reichle, Pollatsek, & Rayner, 2012; Reichle, Warren, & McConnell, 2009). Pelli's study (2003) investigated recognition of target wors; whereas studies on readers' eye movements focused on the flow of reading. Most research on eye movements has inspected alphabetic languages, such as English, where words are separated by space. In contrast, in Chinese orthography, there are no boundaries between characters. As a result, researchers have suggested that characters should be the more important unit of processing in Chinese (e.g., Chen, Song, Lau, Wong, & Tang, 2003; Li, Bicknell, Liu, Wei, & Rayner, 2014).

1.3.1 Eye Movements of Readers in Alphabetic Languages

Eye movement studies in alphabetic languages have demonstrated that linguistic properties, such as frequency and predictability, have influenced the number and duration of fixations. For example, regarding frequency, Vanyukov, Warren, Wheeler, and Reichle (2012) investigated eye-movement research in a visual search task. They found that distractor clusters that occurred more often had shorter first fixation durations, gaze duration, total times, and fewer fixations. Their findings have provided a potential explanation for word-frequency effects in reading (Rayner & Duffy, 1986). Rayner and Duffy (1986) investigated the relationship between lexical complexity and processing time of the word using eye movements. They found that word complexity did not affect fixation time, but word frequency did. The fixation was shorter with a word with higher frequency. With regard to predictability, Rayner, Slattery, Drieghe, and Liversedge (2011) investigated the length and the predictability of words, and found that both length and predictability would affect the probability of skipping target words and the time of fixating the target words, suggesting that word length and predictability independently influence word skipping and fixation duration. In addition to Rayner et al.'s (2011) study, other studies have suggested that words with less predictability in context would be fixated longer than words with more predictability (e.g., Kliegl, Grabner, Rolfs, & Engbert, 2004; Kliegl, Nuthmann, & Engbert, 2006).

Aside from the word itself, the linguistic properties of nearby words have also been found to affect fixation times on a word. One effect that is known as the spill-over effect refers to longer fixations and more fixations on the word after difficult preceding word. For example, Henderson and Ferreira (1990) reported that verbs preceded by low-frequency nouns were processed slower than verbs preceded by high-frequency nouns. Similarly, Kennison and Clifton (1995) reported that nouns preceded by low-frequency adjectives were processed slower than nouns preceded by high-frequency adjectives. However, Pollatsek, Reichle, Juhasz, Machacek, and Rayner (2008) examined fixations on the adjectives with varying frequency and length and the following noun and found an inverted spill-over effect where the gaze durations on long adjectives were longer than short adjectives.

Furthermore, some studies have even shown that the properties of the subsequent word can affect fixation durations; the effect is known as the parafoveal-on-foveal effect (e.g., Kliegl, Risse, & Laubrock, 2007; Pynte, Kennedy, & Ducrot, 2004; Yan, Richter, Shu, & Kliegl, 2009; Yang, Wang, Xu, & Rayner, 2009), but these results were not successfully replicated all the time (e.g., Schotter, Angele, & Rayner, 2012; Schotter, Blythe, Kirkby, Rayner, Holliman, & Liversedge, 2012). A further investigation supporting words being the basic units is the initial landing position on words. Lavigne, Vitu, and d'Ydewalle (2000) investigated semantic context effects on the first landing position in words with different levels of processing difficulty. The results showed that the initial fixation shifted towards the end of the words if the words were predictable from a prior semantic context, suggesting that both ongoing perceptual and linguistic processes could influence where to send the eyes next in reading. Rayner, Binder, Asby, and Pollatsek (2001) also tested the initial landing position of the eyes in either predictable or unpredictable target words. However, the results only showed a small difference in the initial landing position on the target word, suggesting that landing position effects in reading involved low-level processing. The above studies described different effects in eye movements when reading English. Nevertheless, the orthography of Chinese is very different from English; therefore, different assumptions have been made with respect to reading behaviors in Chinese.

1.3.2 Eye Movements of Readers in Chinese

The eye movement studies in Chinese readers have shown different results from those in English. In English (or alphabetic languages), words have been taken as the basic units when reading; however, in Chinese, effects of eye movements have been found in both words and characters. Rayner, Li, and Juhasz (2005) examined Chinese readers' eye movements while reading sentences that contained target words with high, medium, or low predictability from the preceding context. They found that the fixation times were shorter when readers fixated on words with high or medium predictability than on words with low predictability. Their results were similar to Rayner and Well's (1996) study that investigated eye movements in English readers, suggesting that like English readers, Chinese readers exploited target word predictability during reading.

Yan, Tian, Bai, and Rayner (2006) further examined eye movements of native Chinese readers reading sentences that contain target words with different word frequency and character frequency. They also found a comparable word frequency effect on fixation times on a target word in Chinese compared with English. Moreover, they found that the effect of the first character in two-character words was more notable than that of the second character. Nevertheless, the effect of character frequency was less pronounced with high-frequency words but not with low-frequency words. Their findings suggested that eye movements in Chinese reading involved more complex processing that is sensitive to linguistic properties at both word and character levels.

Studies of Chinese eye movements and preferred viewing location also showed similar results to English (Yan, Kliegl, Richter, Nuthmann, & Su, 2010;

Shu, Zhou, Yan, & Kliegl, 2011). In Yan et al.'s (2010) study, they found that the beginning character of a word was more likely to be initially fixated. This finding was similar to Rayner, Fischer, and Pollatsek's (1998) eye movement study in English. Li, Liu, and Rayner (2011) further examined whether there is a preferred viewing location in Chinese reading. To observe eye movements in Chinese readers, Li et al. (2011) inserted either a 2-character word or a 4-character word into the same sentence. Their findings showed that readers' eyes tended to fall near the beginning of the word when all saccades into the target word were considered. They also found that readers tended to fixate at the centre of words if they made only one fixation on the word. Li et al. (2011) therefore suggested that the word segmentation process of reading in Chinese involved both character- and word-based targeting contingencies. The above studies did not only show the similarities between English and Chinese eye movements during reading but also revealed one big difference between English and Chinese reading, which was the involvements of properties of word and character processing.

In a recent study, researchers presented a systematic characterisation of effects in Chinese reading regarding a broad range of word and character properties using mixed-effect regression models. Li et al. (2014) looked into n, n-1, and n+1 in words and characters, also n+2 in characters. The findings suggested that the properties of words in reading Chinese were as reliable as in other languages even though Chinese is unspaced and the visual information of characters are richer than in alphabetic languages, indicating that the process of reading was based on words and it was fundamentally similar across languages with different scripts. Moreover, when the dependent variable was defined in terms of characters, the properties of characters were not as reliable as words. Their study, therefore, suggested that the fundamental nature of reading (i.e. words) might not alter in different scripts.

The above studies have demonstrated research on eye movements in alphabetic languages and in Chinese. Though Li et al. (2011, 2014) have provided evidence showing that the difference of scripts did not affect fundamental reading behaviors, there is still much to discover about the similarities and differences between reading English and Chinese.

To demonstrate the similarities and differences between English and Chinese, Table 1.2 shows features for each language. In this thesis, we mainly compare the similarities and differences in two languages with regard to visual complexity. We also investigate if the smallest unit of Chinese will influence the way native Chinese speakers process.

Features	English	Chinese
writing system	alphabetic	logographic
reading direction	left to right	left to right/ top to bottom
smallest unit	letters	radicals
	sounds	meanings
visual complexity	less	more
	Levels of components	
smallest	letters	radicals
larger	words	characters
		words
largest	sentences	sentences

Table 1.2: Similarities and Differences between English and Chinese.

1.4 Aims of the Thesis

There are several aims in this thesis. The primary aim is to investigate visual perception in Chinese orthography, from its fundamentally distinct unit, characters, to sentence reading. As mentioned in Section 1.1, there are different types of Chinese characters in Chinese orthography. One of the aims of the thesis is to investigate how a single Chinese character is processed in many ways. The first would be a known effect, orthographic *satiation/decomposition* (Cheng & Wu, 1994), which refers to an experience of feeling uncertain about the composition of some characters when staring at a character for too long. This work will focus on whether different types of Chinese characters will affect the timescale or the probability of the occurrence of orthographic satiation.

Unlike alphabetic languages, a Chinese character can contain rich visual information about the meaning as well as the sound of the character. To better understand how each element of a character plays a role in cognitive processing, a mere study of orthographic satiation would be insufficient. Orthographic satiation, which involves lower-level perceptual and cognitive processing, might have shown some of the basics on how the elements of characters carry out their roles. However, how characters are visually processed is a deeper question.

Therefore, the second study in this thesis explores the preference for visual pathways in Chinese characters and words. In English, researchers have reported a contralateral preference when four-letter words were presented very quickly using a haploscope (Obregón & Shillcock, 2012) . It raises the question of whether presenting Chinese characters and words will show similar results considering the complexity and the special characteristics of Chinese orthography.

Lastly, an analysis of the eye movements on Chinese and English reading corpus will be conducted. The processes of reading are intuitively thought to be more complex than perceiving a single character or words. The last studies in the thesis; therefore, focus on the reading behaviours in Chinese and English. The differences between fixating characters, words, and sentences in Chinese and English will be reported.

Chapter 2

Literature Review

2.1 Orthographic Satiation and Decomposition in Logographic Languages

Most native Chinese speakers, when reading or looking at signs, have experienced a feeling of uncertainty about the composition of a character, having stared at that character for too long. This experience is known as orthographic satiation/decomposition (Cheng & Wu, 1994). This phenomenon of feeling a word decomposing or losing its gestalt was first reported for English by Severance and Washburn (1907) who recorded the reports of participants who stared at six-letter English words one at a time. The participants found that the associated pronunciation might become strange (e.g., 'career' became 'car-eer') and letters might change (e.g., 'e' became 'c'). Eventually, the word might become totally foreign and be reported as "a collection of letters" during a 3-minute inspection. Their experiment relied on participants informally fixating the word steadily. Other researchers (e.g. Ditchburn & Ginsborg, 1952) employed technology to stabilize the relevant image on the retina and found that the image would fade and disappear and then, after a while, reappear in whole or in part.

Pritchard, Heron, and Hebb (1960) found that when the stabilized image was a simple figure, such as a line, it would disappear rapidly and reappear as an intact image. If the image was more complex, such as a face, it would disappear in fragments. The timescale of fragmentation was related to the complexity of the image; more complex images tended to remain as wholes or parts longer than simpler images. Additionally, when the authors used meaningful images such as a crossed-out letter 'B', participants might report seeing only the 'B' or the crossing-out, or when the participant could see both parts of the image, the letter 'B' might float above the crossing-out after prolonged viewing. On the other hand, when using a meaningless image, the image might amalgamate with the cross-hatching. Orthographic stimuli showed a similar tendency: the word BEER was perceived as BEER, PEER, PEEP, BEE, and then BE before fading. Pritchard (1961) argued that these data supported Gestalt theory, and that, moreover, knowledge constrained the loss of vision, with images fragmenting into familiar subpatterns. However, Collewijn and Kowler (2008) attribute the reappearance to the movements of objects, head or body.

Inhoff and Topolski (1994) tested their representational decay hypothesis, in which the representation of distinct subpatterns determined pattern perception during retinal stabilization. Using isolated six-letter English words, they showed that words tended to fade gradually from the ending letters to the centre letters; thus, visuospatial properties, not lexical form, primarily determined the loss of visibility of words. However, knowledge of the language also influenced perceived fragmentation. Occasionally, loss of visibility occurred from the centre to the periphery and these losses occurred more frequently for letters at the morpheme boundary of compound words (e.g., 'w' or 'b' of COWBOY) compared with pseudo-compound words (e.g., 'p' or 'k' of NAPKIN). Thus the availability of linguistically-defined sublexical units significantly constrained perceptual satiation in viewing retinally stabilized English words.

Taft (1990) described a category of English words that could/could not meaningfully stand alone, both closed class, which referred to function words (e.g. NOW, THOSE, compared with THAN, ELSE), and open class, which referred to content words (e.g. RAIL, PERSIST, compared with RELY, DISPOSE). In a series of experiments, he showed that lexical decision responses were longer in words that could not stand alone than in words that could stand alone. He concluded that individually meaningful words were processed faster than functionally constrained words, and that the lack of an effect for naming times suggested that the difference occurred in post-access decision processing, not in lexical access itself. We might consider the ″null contexts″ as real contexts, ie. ″no context″ can be a context.

McDonald and Shillcock (2001) examined the role of contextual distinctiveness (CD), the variability of the lexical microcontexts of a word in text, in determining processing of that word; compare the frozen contexts of WREAK, as in 'wreak havoc', and the variable contexts of THE, for instance (cf. del Prado Martın, Kostić, & Baayen, 2004). They showed that CD was a significantly better predictor of lexical decision latencies than was word frequency. Of six measures – concreteness, context availability, number of contexts, ambiguity, age of acquisition and familiarity – only ambiguity was significantly related to CD. This measure also speaks to the processing 'internal' to a word depending to a varying extent on context.

However, the writing systems of Chinese and English are different. Chinese is a logographic writing system. It is different from an alphabetical writing system, such as English, in which the letters represent sounds; instead, a simple Chinese character means a certain thing. For example, ″刀″ means knives, and when a further stroke is put on the knife, it becomes ″刃″, which means blade. The character ″刀″ (knives) evolved from the actual shape of a knife. The Chinese character itself can therefore be ideographic. The most commonly seen characters are phonograms, which compose about 80% of Chinese characters (Hsiao & Shillcock, 2006). A phonogram consists of a semantic and a phonetic radical, the most commonly seen being a left-right structure (e.g., 媽 [ma]: mother; semantic radical: 女 female; phonetic radical: 馬 [mǎ]). But up-down phonograms can also be seen (e.g., 爸 [bà]: dad; semantic radical: 父 father; phonetic radical: 巴 [ba]). Characters are composed of strokes, but the functional unit of the character is the radical (Chen, Allport, & Marshall, 1996). Radicals can themselves typically also stand alone as characters; note that when radicals are combined into a character, although the relative shape of the radical is preserved, it is compressed, as in 媽 above. Characters can combine into words, the predominant word-length being two characters, and words combine into text with typically very few explicit cues to word boundaries. A character can show semantic transparency if the semantic radical and the whole character are semantically related (e.g., 爐 stove: the semantic radical is "火" on the left, which means fire.)

Being so different from the English writing system, the effects of the prolonged inspection of a Chinese character may be expected to be different from those reported in English. Cheng and Wu (1994) conducted the initial investigation in Chinese orthographic satiation. In their experiments, Mandarin Chinese speakers were required to stare continuously at a character in the centre of a computer screen, and press the button immediately when they experienced orthographic decomposition. The reaction time from the presentation of the stimulus to the response of experiencing orthographic decomposition was recorded. The character structure, frequency, and number of strokes were strictly controlled. Characters were categorized into six groups according to the organization of their components, as follows. (a) Ideograms: the character 木 is an ideogram which means trees. (b) A wrapped character including two radicals, one surrounded by the other: 圈 is a phonetic compound, with a semantic radical 囗 surrounding the phonetic radical 卷, pronounced [juàn]. (c) A left-right combined-ideogram: the character 明 means 'bright' with the ideograms of 'sun' and 'moon' in juxtaposition. (d) A top-bottom combined-ideogram: the character 分, which means 'apart'. The structure consists of two ideograms 八 ('eight') and 刀 ('knives). (e) A phonetic compound character: 渣 has a semantic radical on the left and a phonetic radical on the right. The phonetic radical on the right can also be split into two up-down radicals. (f) A combined-ideogram: the character 些 has three parts 止, 匕 and 二. The two radicals on the top can also be composed as a character 此. This typology gives some idea of the variation present in Chinese orthography.

Cheng and Wu found that the time required for experiencing orthographic decomposition for each group of characters was different. Times for combinatorial characters (left-right and up-down) were shorter than for characters consisting of a single radical and for wrapped characters. The results also showed a phonetic effect. Times were longer in phonetically regular characters than non-regular characters. In a phonetically irregular character, the phonetic radical does not provide a direct indication of how the character should be pronounced; we may hypothesize that such a character would satiate more quickly because the radical is less of an integral part of the character's processing.

We might hypothesize that a semantically transparent character would satiate less readily due to the fact that the semantic radical makes an integral contribution to the meaning of the whole character; Cheng and Wu found no support for this hypothesis. However, the definition of semantic radical in Cheng and Wu's study was ambiguous for certain characters. For example, the meaning of the semantic radical 耳 ('ear') did not directly relate to 耽 ('to engage'), but Cheng and Wu categorized it into the semantically transparent group. Thus, any semantic transparency effect might have been affected by the ambiguous categorization of some characters.

Recently, studies related to orthographic satiation have used implicit measurements, such as the lexical decision task (LDT), which were argued to be more objective (Cheng & Lan, 2011; Cheng & Lin, 2013). Cheng and Lan divided two-character words into two categories, same-initial stimuli and different-initial stimuli. Each category was divided into two groups. In same-initial stimuli, words shared the same first character (e.g., 收, 'to receive', 'to collect'). Half of the stimuli were meaningful words (legal words) (e.g., 收穫: 'to harvest'; 收容: 'to shelter') whereas the other half were pseudo-words (e.g., 收肺: 'receive' + 'lungs'; 收齦: 'receive' + 'gums'). In different-initial stimuli, words started with different characters that differed from one another. Half of the stimuli were legal words (e.g., 動盪: 'unstable'; 强制: 'to compel') whereas the other half were pseudo-words (e.g., 投守: 'to throw' + 'guard'; 領曲: 'to lead' + 'curved'). Participants had to determine whether the presented word was a real word or a pseudoword. Cheng and Lan (2011) found that, in the beginning, participants were able to judge same-initial words quicker than different-initial words. As participants judged more words, the lexical decision time increased in same-initial stimuli, suggesting that presenting the same characters repeatedly (e.g., 收穫: 'to harvest'; 收容: 'to shelter') confused participants and delayed their responses.

However, this effect on the response times seems better characterized as a fatigue effect. The classic satiation task and the LDT with repeated characters used by Cheng and Lan (2011) are very different tasks and the relevant processing may not be the same. We suggest that the interesting phenomenon reported by Cheng and Lan (2011) may be more of a maladaptive priming or working memory effect that does not have all of the psychophysical or perceptual characteristics of the classic satiation phenomenon (cf. Pritchard, 1961; Inhoff & Topolski, 1994).

In Japanese research, the effect of orthographic satiation is known as Gestaltzerfall (Ninose & Gyoba, 1996). Japanese readers experienced the loss of gestalt of Kanji after prolonged viewing of the character. Ninose and Gyoba (1996) investigated delays in recognizing Kanji after viewing an adaptation Kanji for 25 seconds. For each adaptation Kanji, four types of test Kanji were designed, to examine how structures and components of the test Kanji character affected participants' judgements: (a) same-structure-same- component (e.g., 焦-焦: identical), (b) same-structure-different-components (e.g., 焦-翌: both are up-down characters, but the radicals are different), (c) different-structures-same- component (e.g., 焦-推: both have the radical 隹; however 焦 is an up-down character and 推 is a left-right character), and (d) different-structures-different-components (e.g., 焦-傷: both structures and components are different).

Ninose and Gyoba (1996) found significant delays in same-structure-same-component and same-structure-different-component conditions. Moreover, the results also showed that when the sizes of adaptation and test Kanji were different, delays only occurred in the same- structure-same-component condition but not in the same-structure-different-component condition. These findings suggested to the authors an adaptation effect in prolonged viewing of Kanji, meaning that the Gestaltzerfall effect was based on relatively high-level cognitive processes, rather than perceptual processes. Ninose and Gyoba (1996) also suggested that the Kanji patterns were stored as a whole internally and the adaptation effect therefore affected the Gestalt representation after sustained viewing. They believed the representation of a whole Kanji was at a higher cognitive level whereas the structure of Kanji was a relatively lower-level process.

In conclusion, researchers have concluded that Chinese orthographic satiation is a different phenomenon from what is going on with retinally stabilized images, and have preferred to employ a lexical decision paradigm to examine the phenomenon (e.g., Cheng & Lan, 2011; Cheng & Lin, 2013). Researchers in Chinese orthographic satiation have focused on character structure, phonetic regularity, and semantic transparency, arguing that these features of characters were the main cause of orthographic satiation. On the other hand, researchers studying the Japanese Gestaltzerfall effect have not taken linguistic variables into account, but rather have concentrated on the relevant geometric patterns. Moreover, studies in Japanese Kanji have been concerned with the adaptation effect in the subsequently presented test Kanji, not the adaptation to the Kanji itself. Studies of adaptation to Japanese Kanji have been more concerned with perceptual plasticity than perceptual learning. Ahissar and Hochstein (2004) have mentioned the phenomenon of adaptation. They reported that adaptation is elicited by constant exposure to stimuli. This hypothesis explains the delays in the-same-structure-same-component and same-structure-different-component conditions in Ninose and Gyoba's (1996) study.

Finally, Lee (2007) extended Cheng and Wu's study (1994) using characters with left-right phonograms (cf. Hsiao & Shillcock, 2005a) to examine a potential sex difference in orthographic satiation. Characters were categorized into paired phonetic-semantic (PS) and semantic-phonetic (SP) characters (e.g., 詳 and 翔; the proportions of SP to PS in the Chinese lexicon are approximately 9:1). In the experiment, participants responded with both hands when they experienced orthographic satiation. The results showed that orthographic satiation occurred faster in females than males; Lee suggested that female participants stored the whole character in assembled form, making it more susceptible to satiation, compared with the male strategy of assembling the representation on the fly. In Chapter 3, we replicate Lee's experiment to see if the reported effect is robust.

2.2 Foveal Splitting in Chinese and English Recognition

Strother, et al. (2017) investigated visual hemifield integration and cerebral lateralisation using fMRI, and found that left-lateralised neural mechanisms were responsible for normal reading. In their earlier study, Strother, Coros, and Vilis used fMRI to explore interhemispheric transfer, and reported the posterior occipital word form area (OWFA) as an independent representation of word form information in each hemifield. Their studies suggested that neural mechanisms in left visual cortex were flexible and integrated into a left-lateralized visual word form network which reinforced rapid word recognition and reading.

How do we perceive when a word falls on the retinal and is projected to the two hemispheres? Axons that are uncrossed in the optic chiasm are added to by temporal retinal ganglion cells and project to the ipsilateral hemisphere, whereas axons that are crossed are increased by nasal ganglion cells and project to the contralateral hemisphere (e.g., Stone & Hansen, 1966)(see Figure 2.1). Toosy et al. (2001) conducted an fMRI study and concluded that the activation in the left hemisphere (LH) is greater when the right eye is stimulated than the left eye, and the activation of the right hemisphere (RH) is the opposite. Although the information that falls on the retina projects to both hemispheres, Toosy et al.'s study suggested that the activation from the contralateral projection is greater than that from the ipsilateral projection.

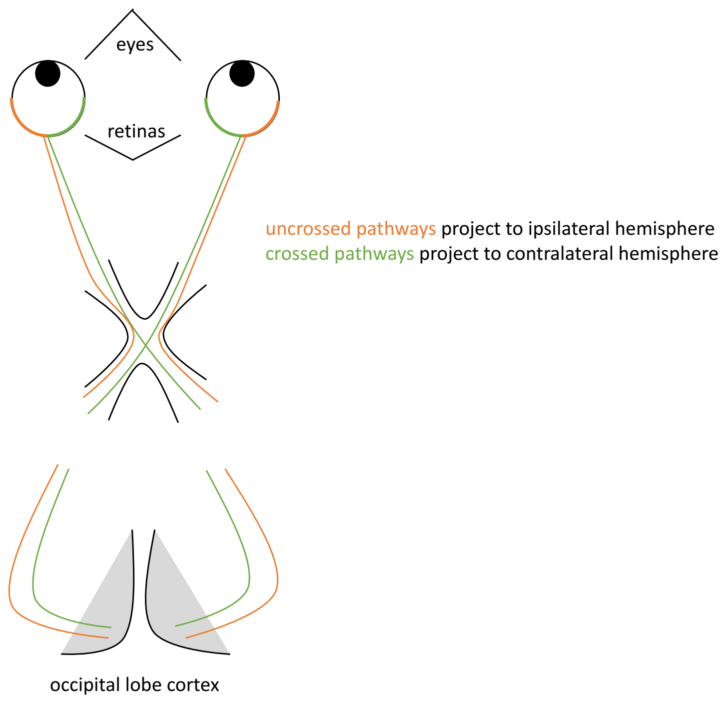

Figure 2.1: Schematic illustration of contralateral and ipsilateral visual pathways.

Obregón and Shillcock (2012) further found that when a four-letter English word was projected contralaterally to the hemispheres, the accuracy of recognizing the word was higher than ipsilateral projection (Figure 2.2 shows the three conditions in the study; Figure 2.3 is the shorthand for the eye/hemisphere contralateral preference). Hsiao, Shillcock, and Lee's (2007) study also confirmed foveal splitting using Chinese character stimulation. Thus, we extend Obregón and Shillcock's (2012) study using the stimuli of Chinese characters and words.

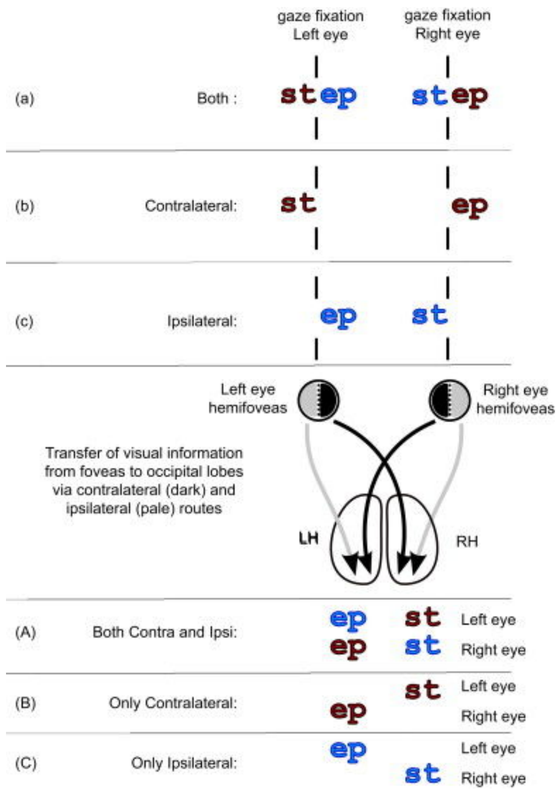

Figure 2.2: Schematic illustration of Obregón and Shillcock's study (2012).

$$\begin{bmatrix} LE & \rightarrow & RH \\ RE & \rightarrow & LH \end{bmatrix} > \begin{bmatrix} RE & \rightarrow & RH \\ LE & \rightarrow & LH \end{bmatrix}$$

Contralateral visual pathway | Ipsilateral visual pathway

Figure 2.3: Illustration of eye/hemisphere contralateral preference.

2.2.1 Studies of Foveal Splitting in Reading Chinese

Hsiao and Shillcock (2005) investigated foveal splitting in the reading of Chinese characters and found a gender difference. The structure of semantic-phonetic compound characters is the most commonly seen. On the other hand, there are characters with the opposite structure, which is phonetic-semantic. The phonetic-semantic characters are much fewer and rarer than semantic-phonetic characters. Therefore, Hsiao and Shillcock (2005) examined how native Chinese speakers of traditional Chinese characters respond to both semantic-phonetic and phonetic-semantic characters. They found that the processing of characters with semantic-phonetic structure was significantly faster than phonetic-semantic in males. However, the processing of both structures showed no significant difference in females. Their study supported the existence of a gender difference in language.

Hsiao, Shillcock, and Lavidor (2006) conducted a repetitive transcranial magnetic stimulation (rTMS) study to investigate hemispheric processing in Chinese character recognition. They used semantic-phonetic (SP) structured characters, the dominant type of Chinese character, in a character semantic judgment task to examine semantic radical combinability effects. Semantic radical combinability refers to the informativeness of a semantic radical. For example, the character 樹 (a tree) contains a semantic radical 木 (a log) which is semantically related to the character. The semantic radical of the character 申 (to express) is 田 (a farm), which is not directly related to the meaning of the character 申. In Hsiao et al.'s study (2006), they presented left-right phonetic compounds, so the semantic radicals on the left side of the fixation line would be projected to the RH while the phonetic radicals on the right side would be projected to the LH according to foveal splitting theory.

The results showed that the facilitation of semantic radicals with large combinability was impaired when rTMS was over the left occipital cortex, but no impairment was shown in the right occipital cortex. The interaction between locations of stimulation and radical combinability revealed a flexible division of labour between the hemispheres in the recognition of Chinese characters. Each hemisphere was able to retrieve optimal information in the contralateral visual hemifield, confirming the foveal splitting theory.

Hsiao, Shillcock and Lee (2007) investigated fovea splitting in Chinese reading using event-related potential (ERP) recordings. They compared characters with semantic-phonetic radicals and phonetic-semantic radicals. With each character presented one at a time, participants had to name the presented character mentally. Moreover, to ensure participants were fixating at the correct position, a digit was displayed at the fixation point. Participants had to respond to the following character/digit by pressing buttons to indicate if the two presented characters were homophones or if the two digits were the same. Data with unacceptable accuracy of responding digit correctly were be excluded.

They found that when participants silently named the target characters, semantic-phonetic characters would elicit larger N1 in the left hemisphere. Phonetic- semantic characters would elicit larger N1 in the right hemisphere . This finding was consistent with the fovea splitting claim, which suggested that two halves of the characters might be projected to different hemispheres at the very first stage. The finding was also consistent with Hsiao and Shillcock's (2005) study, which found the gender difference, by showing the interaction between character type and the gender of the reader in N350.

Hsiao and Liu (2010) developed the previous study (Hsiao, Shillcock, & Lee, 2007) to see whether different structures of Chinese characters involved different hemispheric lateralization by examining semantic-phonetic and phonetic-semantic characters using ERP. Participants had to pronounce each presented stimulus, which could be a semantic-phonetic character or a phonetic-semantic character, as quickly and as accurately as possible, and the given stimulus was presented either to the RVF or LVF. They hypothesized that in the semantic-phonetic structure characters condition, participants tend to choose the right part of the characters, which was the phonetic radical as a phonological cue, and, therefore, could be extracted and processed more efficiently compared with phonetic-semantic characters.

Their results showed an RVF advantage naming semantic-phonetic characters; however, no visual field difference was found in phonetic-semantic characters. This finding supports their hypothesis. Their ERP results, in which semantic-phonetic characters elicited larger N170 amplitude in the left hemisphere than phonetic-semantic characters, were also consistent with Hsiao, Shillcock, and Lee's (2007) study. Their study again proved semantic-phonetic and phonetic-semantic characters were processed differently in the brain. The above studies have not only shown evidence of foveal splitting but also proved the difference between processing SP and PS Chinese characters. Though the evidence seems to be enough to prove the interaction between foveal splitting and structure of Chinese characters using brain imaging and noninvasive stimulation techniques, the presentation of stimuli did not control how the two radicals fell in different visual fields. Therefore, we looked into foveal splitting and Chinese characters using a different technique.

2.2.2 Preferences of Contralateral Pathway

Studies in hemispheric effects have shown a contralateral preference in split-brain patients (e.g., Gazzaniga, Bogen & Sperry, 1963; Stein, Price, & Gazzaniga, 1989) or visual perception (e.g., Obregón & Shillcock, 2012; Toosy et al., 2001; Towler & Eimer, 2015). Research on somatosensory processes has showed lateralization in split-brain patients largely. For example, Gazzaniga et al. (1963) studied a split-brain patient and found that when the patient used one hand to process stereognostic information, it could not be sent to the ipsilateral hemisphere.

The contralateral preference does not only happen in split-brain patients. Niemeier, Goltz, Kuchinad, Tweed, and Vilis (2005) conducted experiments using fMRI to test whether the contralateral visual field was preferred when processing visual elements, or whether it would be bilateral. Tootell and Hadjikhani (2001) had suggested that bilateral visual elements were combined into a whole.

Niemeir et al. (2005) measured blood-oxygen level dependent (BOLD) change within LO when showing animated objects in contra-, ipsilateral, upper and lower visual fields. The results showed that the change was almost four time stronger in the contralateral visual field than in the ipsilateral visual field; whereas the lower visual field was a big stronger than upper visual field. Moreover, responses of the LO were influenced by attention, but relative changes in LO activity caused by changes of object location were preserved even with distraction on the opposite side. They, therefore, concluded that the LO was an intermediate-level visual area where neurons were driven by visual input and spatial attention in multiplicative fashion.

Based on this study investigating contralateral preference in LO (Niemeir et al., 2005), Hemond and Kanwisher (2007) further describe an fMRI study that looked into the object- and face- selective regions in the middle fusiform gyrus (FFA) to investigate whether the fusiform gyrus would also demonstrate a contralateral preference when presenting different visual elements, such as faces, objects, scenes, and scrambled images. The results showed a significant contralateral preference at various levels of the human ventral visual pathway. Though the preference of the contralateral visual pathway in the fusiform gyrus was weaker than in the lateral occipital, it still showed a significant preference for contralateral stimuli, suggesting that sensitivity to the positions of the stimulus could be found even in the high-level ventral visual cortex.

Towler and Eimer (2015) used ERP to explore if the N170 response, which has generic face-sensitivity, would show a contralateral bias when faces and houses were displayed. The results showed high contralateral biases when processing faces. The effects of face inversion also showed strong contralateral biases. Their results suggested that high-level processing of categorical objects, such as faces, was strongly and maybe exclusively constrained to the contralateral hemisphere when two objects were competing in both hemifields, but not in conditions in which only one object was presented to an empty hemifield.

The above studies have shown a clear preference for the contralateral visual pathway when presenting faces or objects. However, what will the results be when words are presented? In Obregón and Shillcock's (2012) study, they conducted a haploscope experiment to investigate visual pathway preferences using English words, and report that participants tended to be more accurate when the stimuli were presented contralaterally. Therefore, in Chapter 4, we extend Obregón and Shillcock's (2012) study by using Chinese characters and words to see if the preference will still be found. We conducted experiments using a stereoscope and the stimuli will be presented quickly (less than 60 ms).

2.3 Microsaccades: Small Eye Movements within fixations

Gaze fixation is required for us to see detail, but a perfectly static fixation causes fading (Martinez-Conde, Machnik, Troncoso, & Dyar, 2006). Tremors, drifts, and microsaccades occur during fixations (Yarbus, 1967). Tremor is the smallest wave-like movement, and its frequency is around 90 Hz (Martinez-Conde, Macknik, & Hubel, 2004). The amplitudes and frequencies of tremor are so small and fast that only accurate eye tracking systems can measure it; otherwise, it is recorded as noise (Martinez-Conde, Macknik, & Hubel, 2004; Otero-Millan, Macknik, & Martinez-Conde, 2014). Riggs and Ratliff (1951) found that tremors were independent in the two eyes; however, Spauschus, Marsden, Holliday, Rosenberg, and Brown (1999) found that tremor in the two eyes was coherently related.

Drifts are slow motions that occur simultaneously with tremors (Martinez-Conde et al., 2004). The size of drifts is less than 0.13 degrees, and the speed is less than 0.5 degrees per second (Rolfs, 2009). Ditchburn and Ginsborg (1953) reported drifts being conjugate both horizontally and vertically, with more conjugacy occurring vertically. Some later studies reported that drifts from the two eyes were synchronized at some level (Spauschus, Marsden, Halliday, Rosenberg, & Brown, 1999; Thiel, Romano, Kurths, Rolfs, & Kliegl, 2006, 2008). Simon, Schulz, Rassow, and Haase (1984) also found that the synchronization of drifts in the two eyes could be diverging or converging.

Finally, microsaccades have been variously interpreted: Ditchburn, Fender and Mayne (1959) considered them to be an essential part of normal vision, but Steinman, Cunitz, Timberlake and Herman (1967) believed that microsaccades were meaningless. In later studies (Martinez-Conde, Macknik, & Hubel, 2000; 2002), microsaccades proved to be correlated with increases in neural firing in the visual pathway at all levels, suggesting that they play an important physical role in fixations. Engbert and Kliegl (2004) investigated the role of drifts and microsaccades during fixations and found that microsaccades and drifts would correct fixation position when fixation duration was between 100-400 msc, but only microsaccades would correct binocular disparity. On short timescales (2-20 msc), both microsaccades and drifts changed randomly in disparity. Engbert and Kliegl, therefore, suggested that microsaccades served a useful purpose.

In Chapter 5 and 6, we look into the fixation data in the Edinburgh Five-Language Reading Corpus and report our findings with respect to the horizontal and vertical eye movements and disparities within fixations.

2.4 Types of Saccadic Eye Movements

The rapid eye movements between fixations are called *saccades*. The length of each saccade that moves forwards for reading English is generally 7 to 9 letters, lasting about 20 to 35 ms. About 10% of reading time consists of saccades. When a saccade begins, the direction of eye movement can not be changed. It can only be changed after the saccade ends. During saccades, only little visual information can be extracted, most of the information is extracted and understood during fixations (Schotter & Rayner, 2015). Rayner et al. (1998) have reported that saccade length determines the saccade time. When a saccade length is farther, the saccade time is longer.

There are four types of saccades during reading: forward movements, regressions, return sweeps (Levy-Schoen & O'Regan, 1979), and small corrective saccades (Becker & Fuchs, 1969). In left-to-right languages, such as English, forward movements are rightward movements that keep the eyes going onwards. The function of the other four types of saccades, on the other hand, is to correct the "inefficiency of text processing" (Rayner, 1998).

The first type of the other four saccades is regression, which involves backward movements during reading. Rayner (1998) believed that readers might fail to understand the reading content if regressions of more than a few letters are made. In a more recent study, Schotter, Tran, and Rayner (2014) used the *trailing-mask paradigm* to investigate the role of regressions in reading. In their study, participants could only read each word once. After participants moved past a word, the word would be masked. Therefore, regressions were eliminated. Schotter, Tran and Rayner found that the comprehension was compromised when participants were not able to re-read (ie. make regressions) the text. Their finding suggested that regression is important with respect to comprehension.

The second type is the return sweep. Return sweeps occur when the eyes exceed a line and are going to do a right-to-left jump from the line to the following line. In Rayner, Schotter, Masson, Potter, and Treiman's (2016) study, they argued that regressions are more important than return sweeps with regards to reading comprehension. Though regressions and return sweeps both involve right-to-left eye movements, the progression of text actually moves forwards for return sweeps. On the other hand, regressions move backwards. In 2.4, we have reported studies which investigated the role of return sweeps in people with reading difficulties (Elterman et al., 1980) or hemispheric defects. These studies have indicated possible regressions after return sweeps. The last type is a corrective saccade, which occurs more often in high proficiency readers and helps readers to re-identify the texts (Rayner, 1998).

In Chapter 7, we continue to look into the Edinburgh Five-Language Reading Corpus and we investigate saccades after return sweeps and compare the differences and similarities between English and Chinese reading.

Chapter 3

The Effect of Loss of Association in Chinese

3.1 Introduction

Knowing that most native Chinese speakers, when reading or looking at signs, have experienced a feeling of uncertainty about the composition of a character, the aim of this chapter is to determine the phenomenon of loss of association in Chinese characters, and at which level of process, orthographic, lexical or semantic, will the phenomenon happen. By identifying at which level of process will the effect occur, we will have a better understanding Most Chinese orthographic satiation studies to date (Cheng & Lai, 2012; Cheng & Lan, 2011; Cheng & Lin, 2013) used the lexical decision task (LDT) to examine what is claimed to be the same phenomenon, which we believed was a fatigue effect instead of the effect of visual fading in retinal stabilization; therefore, this experiment (Experiment 1) replicates Lee's (2007) research and investigated sex differences during orthographic satiation with the aspect of loss of visibility. As in Lee's study (2007), we predicted the sex effect would occur and the satiation effect would occur faster in females than males. Moreover, the interaction with SP-PS characters was observed in order to investigate whether the order of radicals would affect the orthographic satiation effect. Also, by self-reporting from participants, we would have a better understanding of how characters appeared to them after orthographic satiation.

3.2 Experiment 1: Fading Effect in SP and PS characters

Unlike more recent Chinese orthographic satiation studies (Cheng & Lai, 2012; Cheng & Lan, 2011; Cheng & Lin, 2013) that have used lexical decision time to examine the phenomenon, in the current study we return to Cheng and Wu's (1994) more conventional methodology of simple, prolonged exposure to induce the satiation effect. We employed closely controlled PS and SP stimuli to test five hypotheses:

1. that the 'stand-alone' versus 'contextually-supported' dimension, discussed above, would influence orthographic satiation;
2. that Lee's (2007) observed sex difference in orthographic satiation would replicate, with females satiating more readily;
3. that Cheng and Wu's observed effect of phonetic regularity would replicate, with phonetically irregular characters satiating more readily;
4. that semantic transparency would inhibit satiation;
5. that the marked nature of the PS characters (they are only 10% of phonetic compounds) would make them less stable and therefore more liable to satiate.

Overall, we tested the hypothesis that actively performing cognitive work on a character inhibits fading.

3.2.1 Method

Participants. Thirty participants (15 females) were recruited from the University of Edinburgh, ranging in age from 20 to 41 years (mean age=25.9 years, SD=4.46). All participants were native Mandarin Chinese speakers with normal or corrected-to-normal vision sharing the same culture and similar education backgrounds (Taiwan). None reported any language disability. Participants' handedness was assessed using The Edinburgh Handedness Inventory (Oldfield, 1971). Twenty-eight participants self-reported as, and were rated as, right-handed. Two participants self-reported as left-handed and one was rated as left; the other one was rated as ambidextrous on the EHI. All participants gave informed consent to participate in the study, which was approved by the Ethics Committee of the Department of Psychology, University of Edinburgh.

Apparatus. The experiment was implemented using experimental presentation software E-Prime (version 1.1). The participants were seated approximately 50 cm away from a 19" ViewSonic G90fB display screen with a resolution of 1280 x 1024 pixels. The screen refresh rate was 88 Hz.

Materials. Twenty pairs of SP and PS characters were used, making a total of 40 experimental stimuli (see Appendix A). The characters were selected from Hsiao and Shillcock's (2005) study. Each pair of characters shared the same phonetic radical, located in different positions. Each pair was matched in terms of segmental pronunciation (some pairs were different in tone) and token frequency. The two groups of characters were also matched as closely as possible for syntactic class, semantic concreteness, and visual complexity of semantic radicals as measured by number of strokes. The mean number of strokes of the phonetic radical in both SP and PS characters was the same (8.2). The semantic radicals were matched as closely as possible, but the number of strokes was slightly different. A paired-samples t-test was conducted to compare the number of semantic radical strokes in SP and PS. There was not a significant difference in the semantic radical strokes for SP (mean=4.1, sd=1.7) and PS (mean=5.2, sd=3.3) conditions ($t(19)=-1.9$, *n.s*).

Hsiao and Shillcock (2005) had pretested for culturally based gender bias with respect to the SP-PS character pairs, and had found no significant difference. They conducted a naming task, and the results showed that males tended to respond to the presented stimulus faster when the phonetic radical was on the right, with no significant difference in females. Their result suggested that males relied more on the left hemisphere for phonological processing compared with females. Cheng and Wu (1994) found that the orthographic satiation effect occurred faster in phonetically irregular characters; therefore, all selected stimuli in this current study were left-right irregular phonetic compounds that had no direct clues for sounds with frequency of 2.7 characters per million to 41.6 characters per million. The character frequency taken from a corpus of frequency and stroke counts of Chinese characters (Tsai, 2005).

Characters were presented as white on a black background in a standard print font (PMingLiU), 2×2 square cms each, subtending approximately 1° of visual angle horizontally and vertically.

Design. The experiment included one within-subject variable, the position of the radicals (SP vs. PS), with sex difference as a between-subject variable. The dependent variable was the response time from the onset of the stimulus to the experience of orthographic satiation reported by twin button presses by the participant, chosen to avoid asymmetric hemispheric activation.

The paired 20 SP characters and 20 PS characters were divided randomly into two groups of 10 SP and 10 PS characters. In order to reduce any priming effect, the SP and PS characters from the same pair were separated into different groups. The characters were presented randomly in each group.

A final consideration was whether any practice or fatigue effect would occur, affecting satiation. Therefore, two versions of the experiment were created, with 15 (8 males and 7 females in version 1; 7 males and 8 females in version 2) participants in each group. The first group of stimuli were presented first in version 1, whereas the second group of stimuli were presented first in version 2. The two versions of the experiment allowed us to compare satiation latency of the same group that was presented in a different time block.

Procedure. Participants first completed the EHI. The phenomenon of Chinese orthographic satiation was then introduced to them. They were asked to read the singly presented characters normally, and asked not to try and speed up satiation using any strategy. Both verbal and written instructions about the task were given. The participants sat in front of a computer screen, and were asked to press both buttons (i.e. twin button presses) simultaneously when they subjectively experienced orthographic satiation. In other words, when the participants felt that the presented character was decomposed or they were unable to recognise the character (subjectively), they had to press two buttons using their two thumbs simultaneously. Three practice trials were given, with the response times recorded, after ensuring the participants had understood the procedure.

Each trial began with a 5 s presentation of two vertical lines, above and below a space at the centre of the screen, defining a point for the participant to fixate. The radicals of each stimulus character thus appeared on either side of the fixation point, the vertical lines disappearing at the same time. The character remained on the screen for 50 s. The participant indicated that orthographic satiation had occurred by pressing the appropriate keys with the index fingers of both hands. The character remained on the screen for 10 s after participants pressed the keys, to allow participants to experience the character after the onset of orthographic satiation. There was a 1 s interval between trials. A schematic illustration of the experiment is in Figure 3.1.

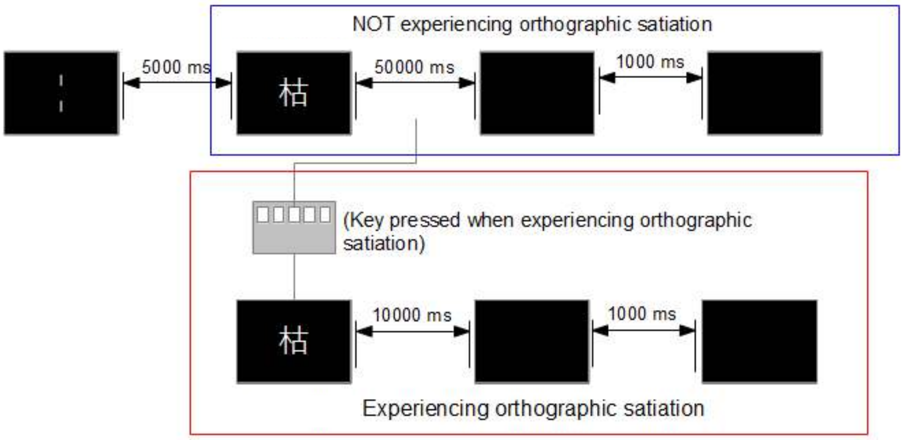

Figure 3.1: The schematic illustration of Experiment 1.

The time between stimulus presentation and the onset of satiation was recorded. In Cheng and Wu's (1994) study the mean satiation time did not exceed 40 s (maximum of 36 s). For left-right phonetic compounds, mean satiation time did not exceed 30 s. Accordingly, in the current study, the stimuli disappeared if the satiation effect was not elicited within 50 s. There was a 3 min break halfway through the experiment. A questionnaire, which asked for participants' self-reports, was given to each participant after the experiment. The entire session lasted about 45 min. Verbal instructions and questionnaires were in Mandarin Chinese (see Appendix B for English version).

3.2.2 Results

Data Collection

The satiation that occurred within 50 s was counted as a true response. Two dependent variables were calculated independently, the satiation time and the probability of satiation. For the calculation of the satiation time, only a true response was included. For the calculation of the probability of satiation, all trials were included. The satiation that occurred within 50 s was counted as a true response; whereas the trials without responses (i.e. the satiation effect was not elicited within 50 s were counted as false responses. Therefore, the probability was categorised according to satiation time.

Descriptive Statistics

The satiation effect occurred 79.7% overall (956 out of all the 1200 trials). The descriptive statistics are shown in Table 3.5. The minimum, maximum and mean satiation times were 0.5 s, 49.9 s and 23.7 s (sd = 12.2 s) respectively. In males, 526 trials showed orthographic satiation (0.44), compared with 430 trials in females (0.36) (Figure 3.2). In SP, 473 trials (0.39) showed orthographic satiation, compared with 483 trials in PS (0.4) (Figure 3.3). The mean RT of satiation for males (mean = 22.1 s, sd = 11.9 s) with that for females (mean = 25.6 s, sd = 12.2 s) was faster. For the position of radicals , the mean RT of satiation for SP (mean = 23.7 s, sd = 12.1 s) and PS (mean = 23.7 s, sd = 12.2 s) were almost the same.

	N	Mean	sd	Median	Min.	Max.
Overall (s)	956	23.7	12.2	22.9	0.5	49.9
			Sex			
Male (s)	526	22.1	11.9	21.6	0.5	49.5
Female (s)	430	25.6	12.2	24.9	1.5	49.9
			Radical Order			
SP	473	23.7	12.1	22.7	1.2	49.9
PS	483	23.7	12.2	23.3	0.5	49.5

Table 3.1: Descriptive Statistics of Satiation Time for Different Variables.

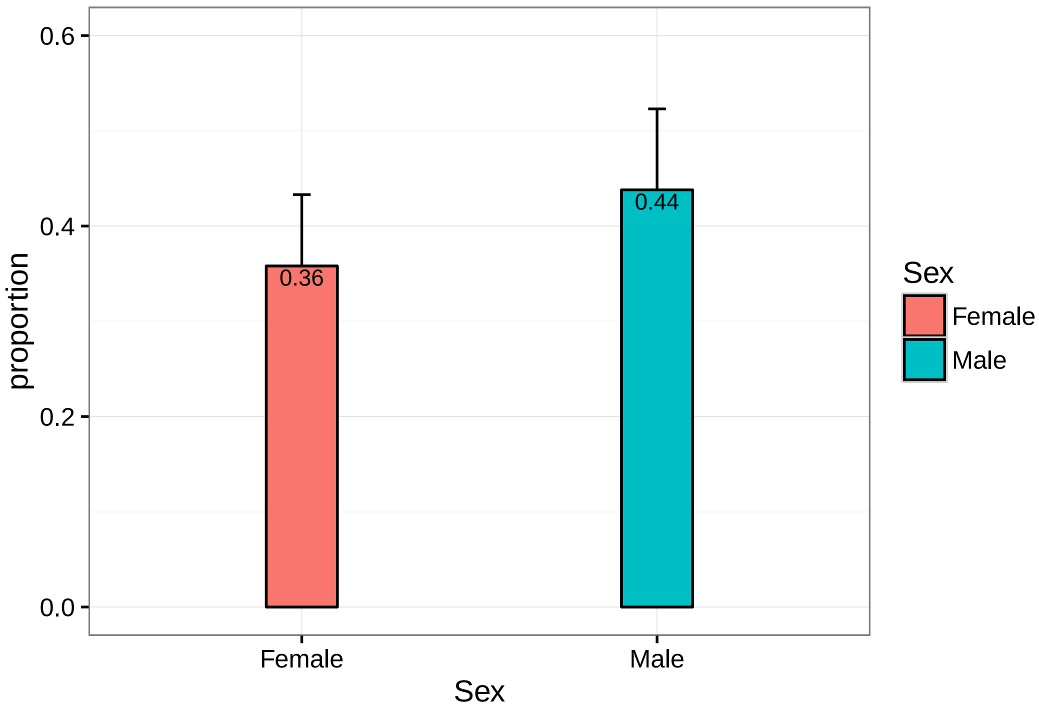

Figure 3.2: Proportion of Orthographic Satiation by Sex.

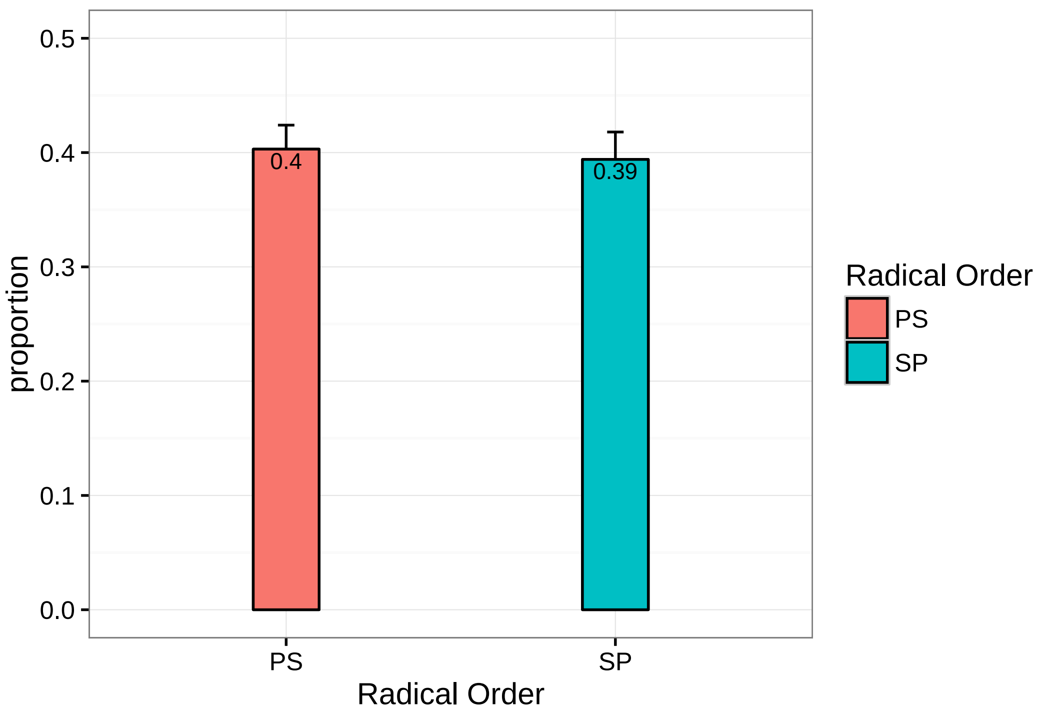

Figure 3.3: Proportion of Orthographic Satiation in Radical Order.

We further assessed the relationship between satiation time and each of five linguistic variables: (a) Radical status: whether one or both radicals of the character could appear as a separate character (values ranged from 0-2); (b) Semantic transparency; (c) Phonetic regularity; (d) Number of strokes; and (e) Character frequency. The descriptive statistics are shown in Table 3.2. The mean RT of satiation for characters with no or one legal radical (mean = 24.3 s, sd = 12.0 s) was slower than characters with two legal radicals (mean = 22.7 s, sd = 12.3 s). The mean RT of satiation for characters with transparent semantic radical (mean = 23.3 s, sd = 12.3 s) was slightly faster than characters with non-transparent semantic radical (mean = 23.9 s, sd = 12.1 s). The mean RT of satiation for characters that shared the same coda with their phonetic radicals was 24.2 s (sd = 11.6 s) and 23.3 s (sd = 12.5 s) for characters that contained phonetic radicals that shared no regularity.

	N	Mean	sd	Median	Min.	Max.
Radical Status						
0/1 legal radical (s)	561	24.3	12.0	23.6	1.2	49.5
2 legal radical (s)	395	22.7	12.3	21.9	0.5	49.4
Semantic Transparency						
Transparent (s)	420	23.3	12.3	22.9	0.5	49.9
Non-transparent (s)	536	23.9	12.1	23.0	1.2	49.4
Phonetic Regularity						
Share coda (s)	377	24.2	11.6	23.9	0.5	49.9
No regularity (s)	579	23.3	12.5	22.4	1.2	49.7

Table 3.2: Descriptive Statistics of Satiation Time for Different Linguistic Variables.

Linear Mixed Effects Analysis

To investigate if there were significance differences in each factor, linear mixed effects (LME) (Baayen, 2011; Bates & Maechler, 2013) analyses were carried out for satiation time (true responses) and for probability of the occurrence of orthographic satiation. Bulmer (1979) has suggested that skewness between 0.5 and 0.5, the distribution is approximately symmetric. The skewness for satiation time was 0.2, suggesting that the distribution of the data was approximately symmetric. In our linear mixed effects models, we added a new variable when creating a new model and compared models with and without the new variable. The variable was retained in the new model if the comparison between the two models was significant in a chi-squared test.

Satiation Time

The dependent variable was satiation time (ST) (ie. the time duration between the stimulus presentation to participants pressing buttons that indicate the occurrence of orthographic satiation). We only demonstrate the last two models here. In the first model (M1), the fixed effects were sex, radical order, and semantic transparency, with one random separate intercept fitted for subjects. To compare with M1, the variable, radical status, was added, with the random effect arranged by subject in the second model (M2). The chi-square test showed significance (see Table 3.3), suggesting a radical status effect.

	DF	AIC	BIC	logLik	Chisq	Chi DF	Pr (>Chisq)
M1	6	26180	-13084	26168			
M2	7	26174	-13080	26160	7.53	1	**

Significance levels: "." < 0.1; "*" < 0.05; "**" < 0.01; "***" < 0.001

Table 3.3: Comparison of Linear Mixed Effects (LME) Models for Satiation Time.

Figure 3.4 and Table 3.4 show the fixed effects for M2 . The intercept of predicted ST represents characters with one/no legal radical, females, PS, and characters with no semantic transparent radicals, which is approximately 19.8 s; it becomes 2 s faster for characters with both legal radicals (17.8 s) (Radical Status Effects: t = *-2.75*). The predicted ST for male (20.8 s) is about 1 s slower than females (the intercept), and it is not significant. The predicted ST for SP (the intercept) is 0.3 s faster than PS (intercept) which shows no significant difference. The predicted ST for characters with semantic transparency is 0.8 faster than character with no semantic transparency that shows no significant difference. There was no interaction in the model.

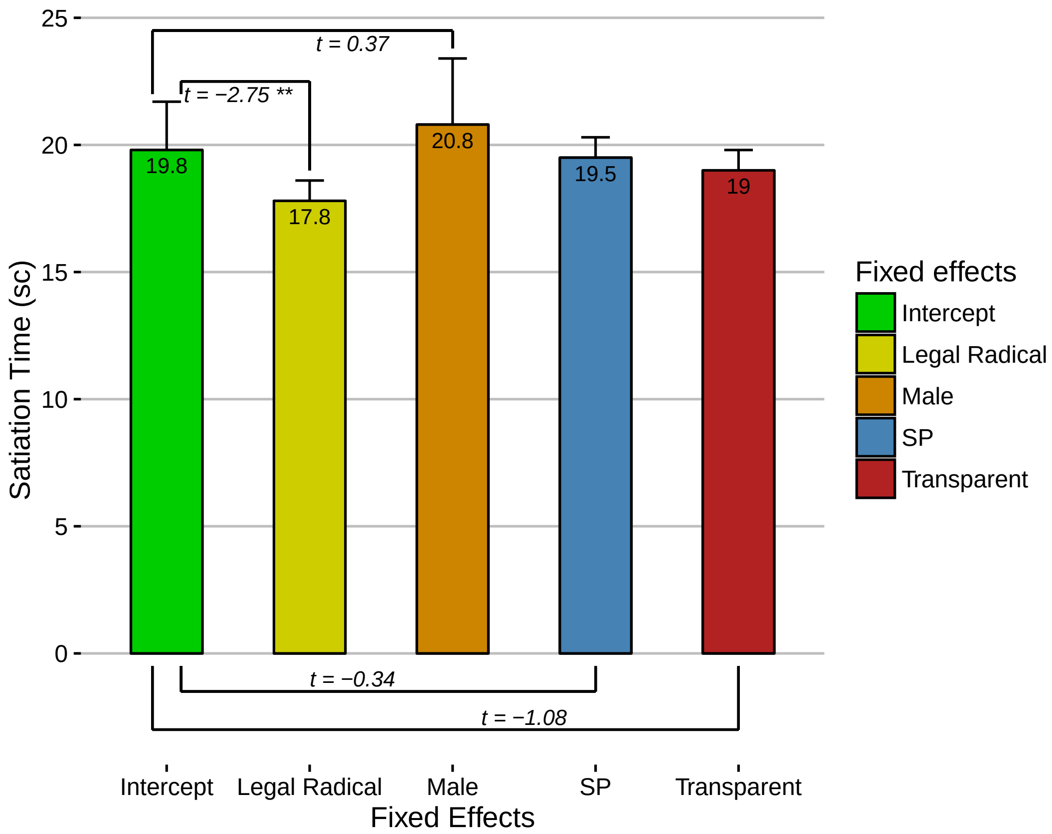

Figure 3.4: Plot of LME for Satiation Time for Different Variables.

Probability

We further analysed the predicted values for probability of satiation using a binomial scheme (Character Satiated [YES or NO]). We use the function [inv.logit] in R to convert Estimate to probability. Figure 3.4 and Table 3.5 show the prediction of the model. The predicted value for probability of satiation for characters with one/no legal radical is 2.7 (93.6%), which is significantly higher (with a predicted value of 2.3 that is 0.4 lower than the intercept) than charac-

Fixed effects:

	Predicted Satiation Time (s)	Std. Error	*t* value
(Intercept)	19.8	1.9	10.5
Male	1.0	2.6	0.4
SP	-0.3	0.8	-0.3
2 Legal Radicals	-2.0	0.8	-2.8
Transparent Character	-8.0	0.8	-1.1

Random effects:

	Number	Variance	Std.Dev.
Subject	30	45290891	6730
Residual		161458292	12707

Table 3.4: LME analysis for Satiation Time for Different Variables.

ters with both legal radical (90.9%). The predicted probability of satiation for PS (the intercept: 2.7; 93.6%) characters is slightly higher than SP (predicted value: 2.5; 92.4%).

Post-experimental self-reports. Some 73% of participants (22 out of all 30 participants) reported that they had experienced orthographic satiation in the past; all said that the phenomenon seldom occurred in daily life. Most participants reported the phenomenon would occur after prolonged viewing, repeated writing of the same character, or when a character kept appearing in an article. Some participants further reported that if the characters were peculiar (e.g., 飛), or unfamiliar, then the orthographic satiation effect would occur. The remaining participants (4 males, 4 females) claimed that they had not previously experienced orthographic satiation.

Participants reported that, in the experiment, the characters usually became normal again after they had reported orthographic satiation; however, some characters did not. Some participants reported that characters containing com-

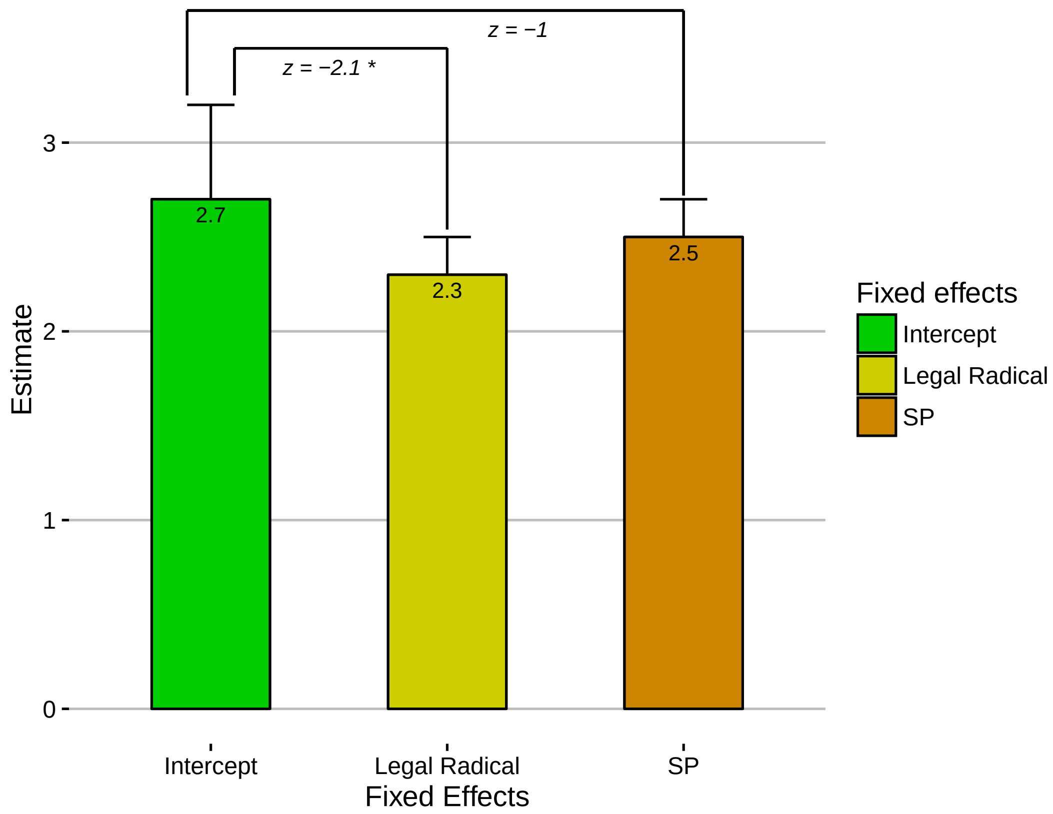

Figure 3.5: Plot of LME for Probability for Different Variables.

plicated stroke patterns (e.g., 據 and 擠) would satiate faster than characters containing simpler stroke patterns, or characters consisting of a large radical and a small radical (e.g., 涕) would satiate faster than more balanced radicals (e.g., 頌), with the complicated or large radical becoming perceptually salient and its counterpart appearing vague or neglected. Few participants reported that characters with balanced radicals satiated faster than characters with complicated stroke patterns or with a large radical and a small radical. Some participants reported that characters with balanced radicals (e.g., 頒) easily became two characters, whereas characters with complex stroke patterns or with one more salient radical were inspected as a whole character.

Some participants reported that characters would appear to be pictures (e.g., the left part of 劍 became a human face with a hat) and geometric shapes

Fixed effects:

	Predicted Probability	Std. Error	*z* value
0/1 Legal Radical; PS	2.7	0.46	5.78
SP	-0.2	0.17	-1.00
2 Legal Radical	-0.4	0.17	-2.10 *

Random effects:

	Number	Variance	Std.Dev.
Subject	30	4.99	2.24

Table 3.5: LME analysis for Probability for Different Variables.

(e.g., only squares were left for the character 嘔; the left part of 副 became geometric). Characters also sometimes became lines and became unrecognizable to some participants. Semantic radicals sometimes came to resemble images associated with their meaning (e.g., the semantic radicals of 鵝 and 鴨 became a bird "鳥"; the semantic radical of 幅 became a towel with a hanger "巾"). Participants also stated that some characters seemed to become other characters with the same phonetic radicals (e.g., 郎 became 朗). A few participants further stated that the characters seemed to drift on the screen before they experienced satiation.

3.2.3 Discussion

We have demonstrated the robustness of the phenomenon of orthographic satiation in Chinese, and we have shown a connection between the phenomenon and the legal stand-alone status of the radicals constituting a character. For example, the character 鴨 contains two legal radicals, the phonetic radical 甲 [jiǎ] and the semantic radical 鳥, which means the bird. The character 涕, for example, contains only one legal radical, the phonetic radical 弟 [dì]. The character 副 contains no legal radicals.

Cheng and Lan (2011) suggested that requiring participants to give responses when experiencing uncertainty about the Chinese characters is a subjective and unreliable methodology; however, in the current study, orthographic satiation was found to be a robust and consistent effect. The satiation times of the stimuli presented in the first block did not differ significantly from those presented in the second block, suggesting that the effect lies at a higher cognitive level not susceptible to the fatigue or practice effects that may have been induced in Cheng and Lan's (2011) lexical decision paradigm.

Several findings in the current study showed that Chinese satiation was robust. Of the variables that we manipulated, a significant effect emerged with respect to radical status: characters that contained only one radical that could legally stand alone, or no such radical, were more likely to satiate than characters that contained two radicals that could legally stand alone. This result was consistent with participants' individual post-experimental reports. Moreover, this result was in line with our discussion, above, regarding the varying extent to which (English) words are processed with respect to their external constraints. Our data extend this discussion to Chinese orthography and to the orthographic satiation effect. We suggest that, in Chinese, the fact that a radical can stand alone as a single character makes characters in which it occurs resistant to satiation.

Furthermore, in a latest study, Yuan, Carr, Ding, Fu and Zhang (2017) investigated at which level, orthographic or semantic level, the orthographic satiation would be elicited. They have found that, during reading, the orthographic satiation occurs at the level where orthography associates meaning, but not at the purely orthographic level. Their study aligns with our finding where characters with one or no legal radical satiate faster than those with characters with both legal radical. The speculation is that when at the level of associating orthography with meaning, radicals that can not stand alone fail to associate orthography with meaning and therefore cause the orthographic satiation.

The reports that characters satiated and became pictographs (e.g., 巾, meaning towel, became a towel hanging on the hanger) revealed the close relationship between the pictographic and non-pictographic aspects of the orthography of Chinese. Luk and Bialystok (2005) asked people who had no prior knowledge of Chinese to guess the meanings of simple Chinese semantic radicals that were selected as being iconic or arbitrary; participants were required to say which of two pictures matched the meaning of the radical. The iconic characters were matched significantly more successfully than the arbitrary characters. Luk and Bialystok's finding showed that Chinese characters have different visual relationships with meaning. With the help of visual features, even people who are naive to Chinese characters are able to recognise the characters. For native Chinese speakers, with long exposure to Chinese characters and advanced knowledge of Chinese characters, there may be even stronger links between iconic characters, or radicals, and the relevant semantic imagery.

In conclusion, post-experimental reports from participants suggested that orthographic satiation occurred in various ways for different characters. Our demonstration of the robustness of the phenomenon, together with the discovery of one aspect of how it comes about, underwrite the further study of orthographic satiation, particularly in the very complex orthography of Chinese.

Chapter 4

Visual Pathways in Perceiving Chinese

4.1 Introduction

The studies reviewed in Chapter 2.2.2 have shown clear contralateral preferences using different techniques together with Obregón and Shillcock's (2012) study that described a haploscope experiment to investigate preferences for visual pathways using English words. In Obregón and Shillcock's (2012) study, they found a functional contralateral preference specifically at the fovea by quickly presenting split four-letter English words to different visual fields. There were three different conditions: (1) Both condition (st|ep)(st|ep), (2) Contralateral condition (st|_ _)(_ _|ep) and (3) Ipsilateral condition (_ _|ep)(st|_ _). In the Both condition, the two stimuli "step" were presented to both visual fields. In the Contralateral condition, the stimulus "st" was presented to the left visual field (LVF) of the left eye (RH), and "ep" was presented to the right visual field (RVF) of the right eye (LH). Conversely, the stimulus "st" was presented to the left visual field of the right eye (LH), and "ep" was presented to the right visual field of the left eye (RH).

Obregón and Shillcock (2012) found that the accuracy of word recognition was best in the Both condition, followed by the Contralateral condition, then the Ipsilateral condition. Their results were coherent with previous studies (e.g., Niemeier, Goltz, Kuchinad, Tweed, & Vilis, 2005) that showed an eye/hemisphere contralateral preference. Moreover, Obregón and Shillcock's (2012) study can also suggested that even in very short presentations (14 ms or 28 ms), the structure of the fovea still influenced perceptual recognition.

In Rozin, Poritsky, and Sotsky's (1971) study, they tutored dyslexic American children in both English reading which involved letter-sound relationships and Chinese-English word mapping. In Chinese-English word mapping tutorials, children read English sentences with the Chinese orthography. Chinese was never spoken. It was reported that when using Chinese characters to represent, the ability of dyslexic American children picking up English words was facilitated. However, the letter-sound relationships practices did not help to facilitate children's English reading ability. This study has shown that the alphabetic writing system was not only different from the logographic writing system but that ideographic languages might be memorized easier at the lexical level.

As a logographic language, can the visual pathway preference still be demonstrated? Or the distinctiveness of Chinese will affect visual pathway processes? In Hsiao et al.'s (2007) study, they investigated foveal splitting effects in Chinese, using ERP. The results showed that, for left-right structured characters, two parts of a character might be presented to different hemispheres in the beginning. Hsiao et al. confirmed the possible existence of foveal splitting. To further confirm and explore how foveal splitting affects the eyes, in this chapter, we extend Obregón and Shillcock's (2012) study by presenting Chinese characters or words. Three experiments were conducted. The first experiment (Experiment 2) (Figure 4.1) looked into left-right structured Chinese characters. The second experiment (Experiment 3) investigated specifically SP-PS structured Chinese characters while the last experiment (Experiment 4) looked into two-character Chinese words. Many studies have indicated a contralateral preference, so we predicted that there would also be an eye/hemisphere preference for the contralateral visual pathways in Chinese recognition. As Rozin et al. (1971) show, however, there are deep differences between the processing of Chinese and the processing of English, so there may be departures from the default prediction of an eye/hemisphere contralateral advantage (Figure 4.2).

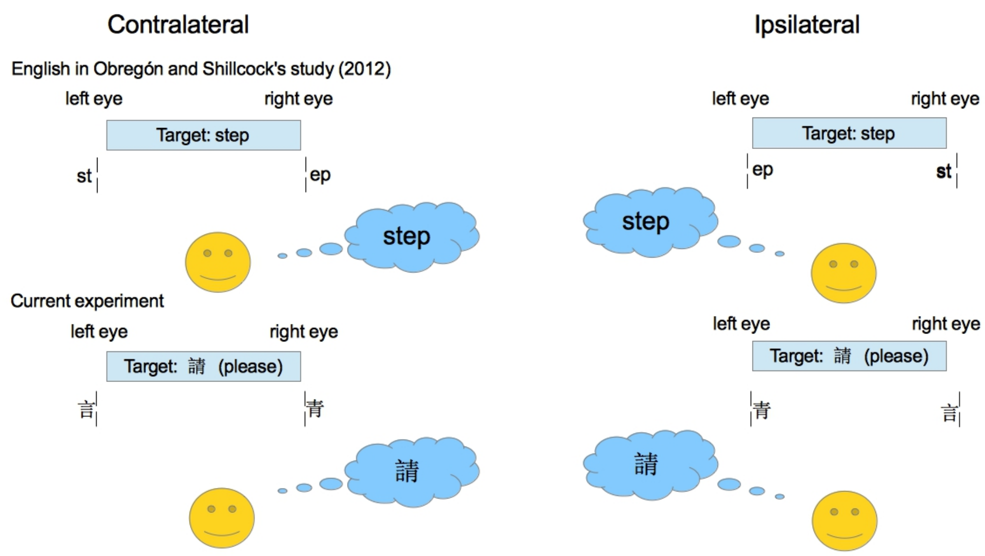

Figure 4.1: Schematic illustration of Obregón and Shillcock's study (2012) comparing with Experiment 2.

$$\begin{bmatrix} LE & \rightarrow & RH \\ RE & \rightarrow & LH \end{bmatrix} > \begin{bmatrix} RE & \rightarrow & RH \\ LE & \rightarrow & LH \end{bmatrix}$$

Contralateral visual pathway — Ipsilateral visual pathway

Figure 4.2: Illustration of eye/hemisphere contralateral preference.

4.2 Experiment 2: Contralateral and Ipsilateral Visual Pathways in Chinese Characters Perception

In previous studies (e.g., Taft & Zhu, 1997; Feldman & Siok, 1999; Hsiao, et al., 2007), the right-left structured Chinese characters referred to semantic-phonetic compounds (phonograms). In this experiment, we employed characters with right-left structure, but not limited to semantic-phonetic compounds. In other words, a character that was an ideogram (e.g., 戕) could be one of the stimulus materials if it was right-left structured. We did not exclusively use semantic-phonetic characters so that the nature of how native Chinese speakers process characters visually could be observed.

4.2.1 Method

Participants. Twenty-eight Taiwanese students (16 females), who were native Mandarin Chinese speakers, from the University of Edinburgh, volunteered to participate in the experiment, ranging in age from 18 to 43 (mean age= 28, SD= 5.3). All participants had normal language use and had normal or corrected-to-normal vision. Participants' handedness was assessed using the EHI. All participants reported as, and rated as, right-handed.

Apparatus. The equipment used for this experiment was a custom-made haploscope and the experimental presentation software E-Prime (version 1.1). The participants were seated approximately 135 cm away from an Iiyama Vision Master Pro 514 display screen with a resolution of 1024 x 768 pixels. The screen refresh rate was 60 Hz.

Materials. 400 right-left structure characters were selected from Frequency and Stroke Counts of Chinese Characters (Tsai, 1996-2005) (see Appendix C). Three types of characters were categorised by strokes: (1) 150 characters with more strokes in the left radical than the right radical, (2) 150 characters with more strokes in the right radical than the left radical and (3) 100 characters that consist of two radicals with the same number of strokes. Strokes of each radical were assessed according to an online dictionary Han Dien, which included over 70,000 examples of both simplified and traditional characters (LONGWIKI, People's Republic of China, 2004). The mean stroke number of the characters was 12.01 with a minimum of 4 and a maximum of 30. The frequencies of characters ranged from 0.02 per million to 3898 per million.

Additionally, to determine and ensure that the low-frequency (frequency below 0.5 per million) characters were plausible, an online survey was conducted in which 60 Taiwanese volunteers were asked the pronunciation of each character. The characters were grouped by their types, which could be: (1) pictograph, characters that were concretely iconic, (2) phonogram, characters with a phonetic and a semantic radical, (3) ideogram, characters that indicate an idea, (4) phono-ideogram, characters with an ideogram and a phonogram (see Figure 4.3) according to Han Dien (LONGWIKI, China, 2004).

Design. One within-subject variable was the visual presentation of characters (contralateral vs. ipsilateral). The dependent variable was the scores participants gained from their reports of the accuracy of the target characters. Participants needed to report what they saw. They got 2 points when they reported a radical correctly. If they could report a radical only partially correctly, they got only 1 point. The minimum of the scores was 0, and the maximum was 4. Characters were presented as silver on a black background in a standard print font (PMingLiU), with the size of 2×2 square centimetres each, subtending approximately 1 degree of visual angle horizontally and vertically. The stimuli were displayed contralaterally or ipsilaterally for each participant through the haploscope.

All 400 characters were divided into two groups, in which the frequency of characters was controlled, with 200 characters in each group. Two conditions,

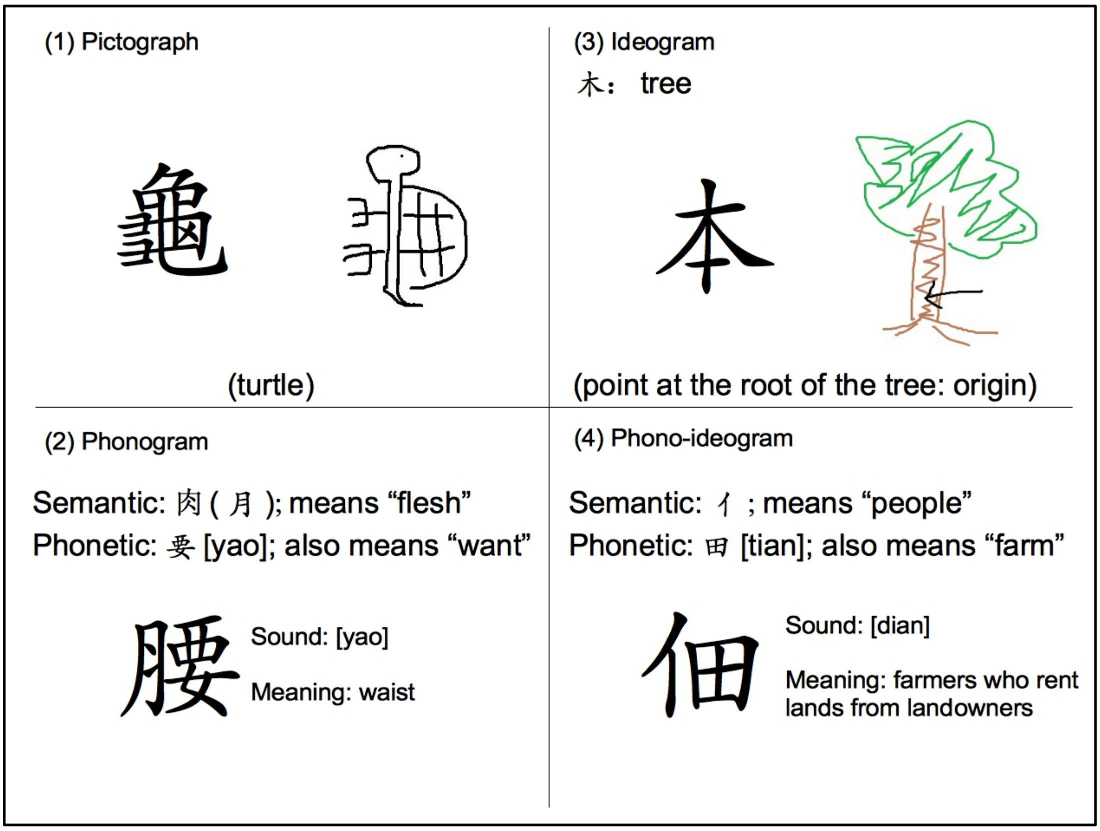

Figure 4.3: Examples of characters that categorised by its type.

contralateral and ipsilateral, were created. The radicals of character flanked on two sides of two vertical lines which were seen binocularly, the degree of visual angle from the edge of each radical to the vertical lines was approximately 0.03 degrees. For the two created groups, each group was assigned to each condition respectively. The stimuli were presented randomly and conditions assigned to each participant were also counterbalanced (i.e. for participants of odd numbers, they saw stimuli of odd numbers contralaterally and even numbers ipsilaterally; where as the participants of even numbers saw stimuli of odd number ipsilaterally and even numbers contralaterally).

Procedure. Participants were first asked to complete the EHI and a version of the hole-in-the-card test in order to record the dominant eye for each participant. Their eyesight was then tested. Participants were requested to try not to blink their eyes during the experiment. Both verbal and written instructions about the task were given. Two practice trials were given.

Each trial began with a presentation of a vertical line above and below the centre of the screen. The time of each trial of the experiment was not rigorously controlled and recorded to allow participants to have enough time reporting and preparing for the next trial. Participants had to look at the midpoint between the two vertical lines, which the radicals of character flanked on two sides. Following the two lines, the presentation of a character remained on screen for 28 or 57 ms before back-mask hashes appeared on the screen. Participants were asked to report the character which should be said if both radicals were visible. If they only saw radicals, they had to report the radicals they saw. Meanwhile, the experimenter recorded what participants reported by giving it a score (see below). The participants then pressed the appropriate keys with index fingers of both hands to start the next trial.

In Obregón and Shillcock's (2012) study, 14 ms and 28 ms were set as time durations. However, Chinese characters are more complex than English words and most participants could not identify the characters when they were presented in 14 ms in the pretest; therefore, we tested which speed (28 ms/ 57 ms) was the most appropriate version for each participant. There were ten trials (20 characters) in the contralateral and ipsilateral conditions and at three presentation durations (14 ms, 28 ms and 57 ms) in the pretest. Correct character identifications determined a proper stimulus presentation duration of 28 ms or 57 ms for that participant in the experiment.The entire session lasted about 65 m.

4.2.2 Results

Correct Response Evaluation. The score of a correct response is 4. If participants failed to report or had reported a different character from the target, they got score 0. Score 1 would be recorded if only one side of the radicals was reported partially correct. If participants reported partially correct from both sides, the score would be 1.5, and score 2 for correct response of one side. If one side was reported correctly and the other side reported partially correct, the score would be 3 (See Table 4.1).

Example Target	Participant Report	Left Constituent	Right Constituent	Score
泳	Fail to report	Incorrect	Incorrect	0
	林	Incorrect	Incorrect	
	冫	Partially Correct	Incorrect	1
	水	Incorrect	Partially Correct	
	冰	Partially Correct	Partially Correct	1.5
	氵	Correct	Incorrect	2
	永	Incorrect	Correct	
	冫+永	Partially Correct	Correct	3
	沐	Correct	Partially Correct	
	泳	Correct	Correct	4

Table 4.1: Example of measurement of all conditions of response for Chinese characters.

Descriptive Statistics. We recruited 30 participants. However, we found that the data of Subject 305 and 307 were partially missing; therefore, the data were removed. There were 11200 trials in total. The mean score of left character was 1.2 (SD= 1); the mean score of right character was 1.4 (SD= 0.9). Using the scoring table in Table 4.1, the mean score for correct response was 2.6 (SD= 1.7). The mean scores of both the left and the right radicals were 1.3 (SD= 0.9).

The mean score across all participants is 2.7. Table 4.2 presents the descriptive statistics for scores in condition (contralateral vs. ipsilateral) and sex (male vs. female). Figure 4.4 shows that, the proportion of getting correct response in contralateral condition (0.28) is slightly higher than ipsilateral condition (0.27). In Figure 4.5, males (0.29) tend to give more correct responses than females (0.27).

	Mean	sd	Median	Min.	Max.
Overall (s)	2.7	1.7	4	0	4
Condition					
Contralateral (s)	2.7	1.6	4	0	4
Ipsilateral (s)	2.6	1.7	4	0	4
Sex					
Male	3	1.6	4	0	4
Female	2.4	1.7	3	0	4

Table 4.2: Descriptive Statistics of Scores for Different Variables.

The Hemispheric Effect

To investigate the hemispheric effect, we looked into the partially correct response (score between 1 and 3). Responses with more scores on the left part (2|0; 2|1; 1|0), were marked as RH; on the other hand, responses with fewer scores on the left (0|2; 1|2; 0|1), were marked as LH. Responses with an equal score (1|1) were marked as BH. There were 2392 out of 11200 trials for the partially correct responses. Table 4.3 only shows the proportions of LH and RH because there were very few BH cases (contralateral = 17, ipsilateral = 11 for females; contralateral = 4, ipsilateral = 8 for males). In Table 4.3, females produced responses that were more correct than males across all conditions.

Linear Mixed Effects (LME) Analysis.

Probability of Correct Response

An LME analysis was carried out for the probability of correctness using a binomial scheme (Correct [YES or NO]). We created a model and compared it with a more complex one until we found the fitted model. We only demon-

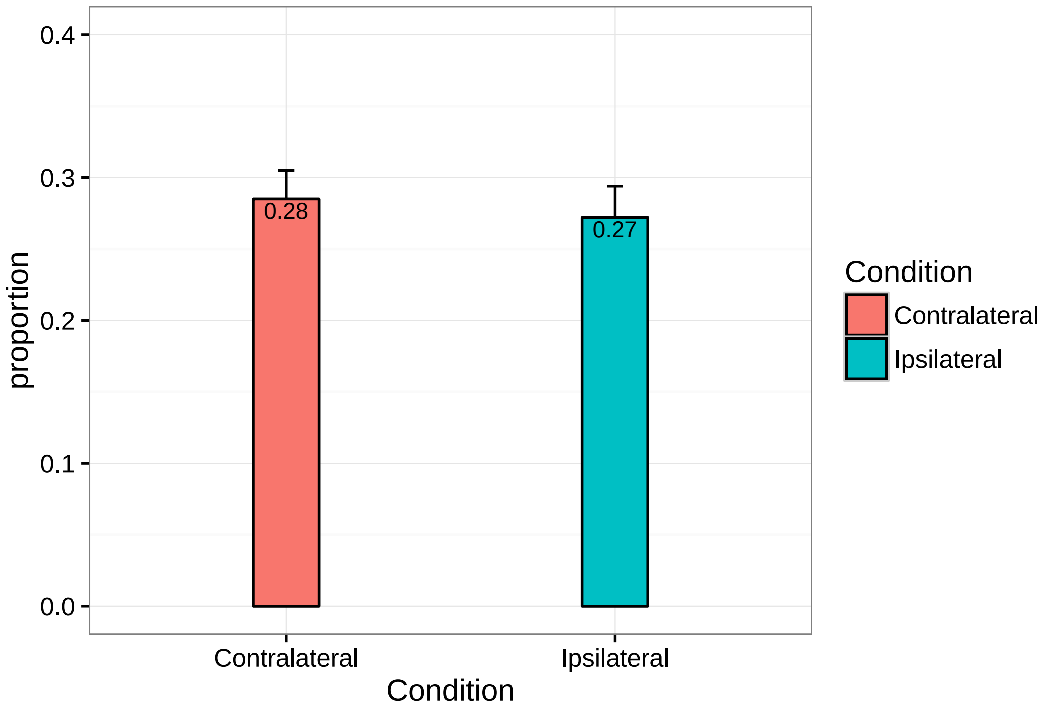

Figure 4.4: Proportions of Accuracy in Contralateral and Ipsilateral Condition.

strate the last two models here. In the first model (M1), the random effect grouped by subject, and the factors of fixed effects were the condition, sex, strokes, and frequency. To compare with M1, the random effect arranged by stimuli and subject in the second model (M2). The factors of fixed effects were the same as M1. The chi-squared test, was twice the difference in log-likelihood, showed significance (see Table 4.4).

We use the function [inv.logit] (inverse logit) in R to convert the logits to probability (Table 4.5). The predicted probability of the intercept, which was contralateral condition in females getting correct responses (48.2%), was significantly higher than the predicted probability of ipsilateral condition in females (44.1 %). The predicted probability of males getting correct responses in the contralateral condition was significantly higher than females. The prediction of strokes also showed significance, such that with fewer strokes, the correctness was greater. The prediction of frequency of characters was also significant

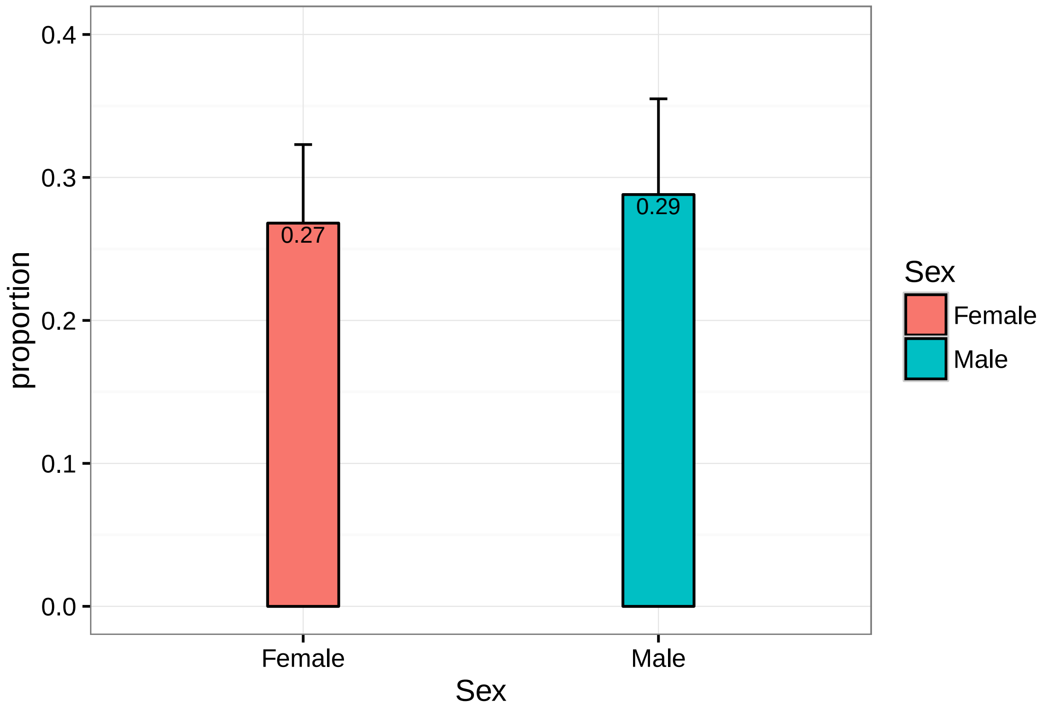

Figure 4.5: Proprotion of Accuracy in Females and Males.

which showed that with more frequently seen characters, there was a higher probability of getting a correct response (see Table 4.5 & Figure 4.6). Though both females and males performed better in contralateral condition, the interaction of condition and sex was not significant, suggesting that the difference between contralateral and ipsilateral conditions in males was not as much as those in females.

Hemispheric effects

To further analyse if there were hemispheric effects, we also ran an LME analysis. The dependent variable was the partial correctness using a Poisson distribution. The data for how we calculated the scores included the non-integer 1.5, where only half of each side was correct. Therefore, we multiplied the dependent variable by 10 to ensure that the Poisson models worked well. The fixed effects were condition, interaction of sex and hemisphere (LH/ RH),

Condition	Contralateral		Ipsilateral		Total
Sex	Male	Female	Male	Female	
			LH		
Count (%)	188 (15.0%)	460 (36.7%)	153 (12.3%)	451 (36.0%)	1252 (100%)
			RH		
Count (%)	135 (12.3%)	366 (33.3%)	161 (14.6%)	438 (39.8%)	1100 (100%)
Total					2352

Table 4.3: Proportions of Partially Correct Response Cases for Radicals by Hemisphere.

	DF	AIC	BIC	logLik	deviance	Chisq	Chi DF	(>Chisq)
M1	7	12936	12987	-6461.1	12922			
M2	8	12829	12887	-6406.4	12813	109.39	1	***

Significance levels: "." < 0.1; "*" < 0.05; "**" < 0.01; "***" < 0.001

Table 4.4: Comparison of Linear Mixed Effects (LME) Models for Probability of getting correct responses.

strokes and frequency. Different models were run as before, but only the final analysis is shown (see Table 4.6).

The predicted value of the contralateral condition (2.99) was significantly higher than the ipsilateral condition (2.96) as the model for correct probability (z = 3.61). The predicted value of LH between males (intercept: 2.96) and females (2.98) showed no significance. The predicted value for RH in males (3.09) is significantly higher than LH in males (intercept: 2.96). The predicted value for strokes showed that with more strokes, the predicted value became higher (z = -3.89). There was no significant Freqeuncy effect. The predicted value of the difference between LH/RH is higher in males (LH: 2.96; RH: 3.09) than females (LH: 2.98; RH: 3.05) (z = -2.82).

Fixed effects:

	Model Prediction	Std. Error	z value	Predicted 1	Predicted 2*
Intercept*	-0.07	0.25	-0.29	-0.07	48.2%
Ipsilateral	-0.16	0.06	-2.88 **	-0.23	44.1%
Male	0.97	0.38	2.57 *	0.9	71.1%
Strokes	-0.07	0.01	-11.12 ***	-0.14	46.6%
log(Frequency)	0.07	0.01	7.15 ***	0.00	49.9%
Ipsilateral: Male	0.07	0.09	0.88 *ns.*	0.81	69.3%

Significance levels: "." < 0.1; "*" < 0.05; "**" < 0.01; "***" < 0.001

Predicted 1*: Predicted Value

Predicted 2*: Predicted Probability

Intercept*: Contralateral: Female; log(Frequency)

Random effects:

Groups	Name	Variance	Std.Dev.
Stimuli	(Intercept)	0.13	0.35
Subject	(Intercept)	0.96	0.98

Number of trials: 11200, groups: Stimuli, 400; Subject, 28

Table 4.5: LME analysis on Probability of getting correct responses for Chinese characters.

4.2.3 Discussion

Our results showed that the contralateral visual pathway was preferred in perceiving right-left structured Chinese characters as we predicted. We not only demonstrated the contralateral preference in foveal processing from retinal to cortical processing but we also successfully extended Obregón and Shillcock's (2012) finding which indicates the contralateral preference in perceiving English, by using Chinese stimuli. Though, in Obregón and Shillcock's (2012) study, they did not consider sex as one of the variables, we took account of sex

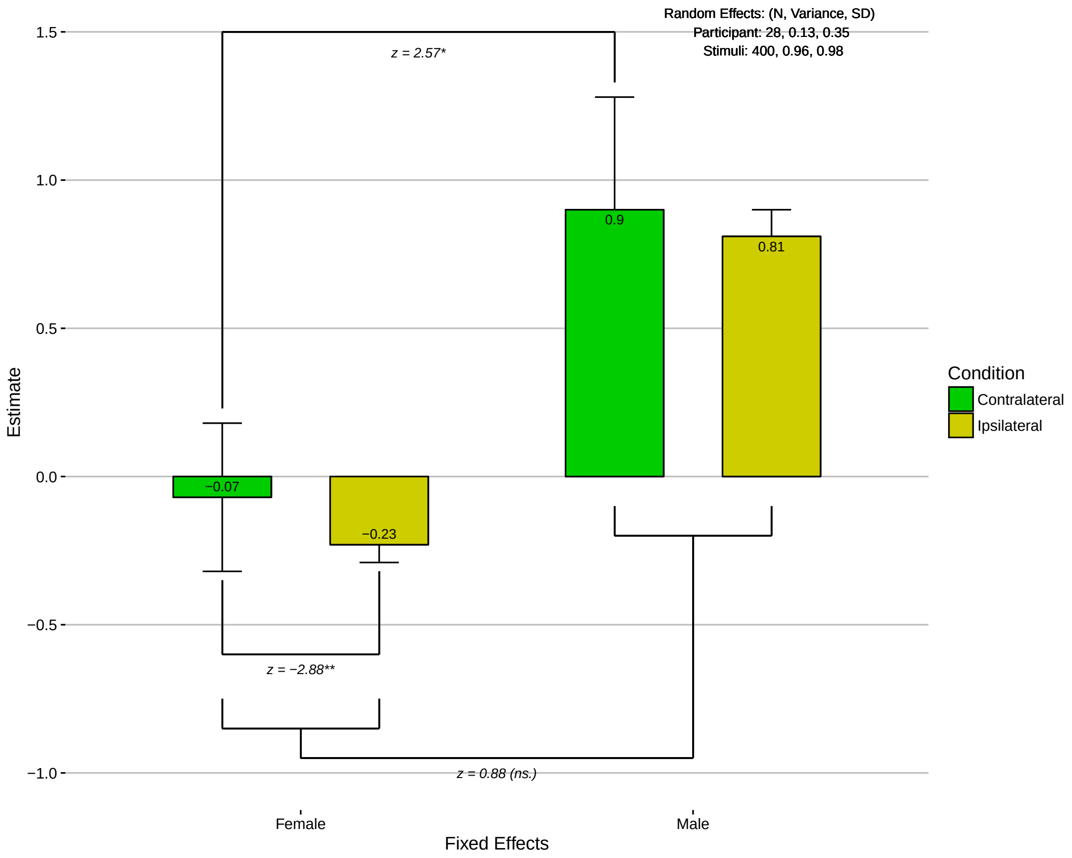

Figure 4.6: Plot of LME for Probability between Female and Male: Contralateral and Ipislateral Condition.

and found that males did better than females (see p.65 and Table 4.5) in recognizing characters. Some studies in the reading behavior of sex differences have shown that females performed better than males (e.g., Mikk & Lynn, 2009). However, in other studies, males were better in visuospatial tasks involving memory, and females performed better in verbal tasks (e.g., Huestegge, Heim, Zettelmeyer, & Lange-Küttner, 2012). In an fMRI study, there were more RH regions activated in reading Chinese than in reading English (Tan et al., 2001), suggesting that processing square-shaped Chinese characters required an analysis of spatial information of strokes. The finding of more RH regions activated in reading Chinese than in reading English is consistent with our finding that has shown better predicted mean score in the RH than in the LH. More-

Fixed effects:

	Model Prediction	Std. Error	z value	Predicted 1*
Intercept*	2.96	0.02	147.59	2.96
Contralateral	0.03	0.01	3.61 ***	2.99
Female	0.02	0.02	0.65 *ns.*	2.98
RH	0.13	0.02	7.01 ***	3.09
Strokes	-0.02	0.01	-3.89 ***	2.94
log(Frequency)	-0.01	0.01	-0.75	2.95*ns.*
Female: RH	-0.06	0.02	-2.82 **	3.05

Significance levels: "." $<$ 0.1; "*" $<$ 0.05; "**" $<$ 0.01; "***" $<$ 0.001

Predicted 1*: Predicted Correctness

Intercept*: Male: LH; Ipsilateral; Strokes; log(Frequency)

Random effects:

Groups	Name	Variance	Std.Dev.
Stimuli	(Intercept)	0.0008	0.03
Subject	(Intercept)	0.0023	0.05

Number of trials: 2352, groups: Stimuli, 399; Subject, 28

Table 4.6: LME analysis on Poisson in partially correct responses for Chinese characters.

over, since males have been proved to perform better in visuospatial tasks, and perceiving Chinese characters required the analysis of spatial information, this could explain why males did better than females (de Bruin, Bryant, MacLean, & Gonzalez, 2016; Huestegge, Heim, Zettelmeyer, & Lange-Küttner, 2012; Sherwin, 2003; Zilles et al., 2016).

Our finding indicated Chinese characters with more strokes producing less accuracy was also consistent with Wang, He, and Legge's (2014) study that investigated the effect of pattern complexity on the visual span in perceiving

Chinese characters, finding that the visual span decreased when the complexity of characters increased. The result explained why when presenting a character with many strokes, the accuracy of the character recognition was low. Also, the presentation of our stimulus was very quick (28ms/ 57ms). It was understandable that people could not recognise the character in such quick presentation speed if the character consisted of many strokes.

When we looked into the hemispheric effect, we also found similar results for the condition, which showed that the predicted value of the contralateral condition was higher than ipsilateral condition, and with more strokes, the score became lower. The average score of the RH (the left visual field of both eyes) was higher than LH in males. Hsiao and Shillcock (2005) found gender differences when presenting SP and PS characters to male and female participants. Males tended to respond faster to SP than to PS, while females showed a non-significant difference in the opposite direction, suggesting a more bilateral activation.

Moreover, Hsiao and Cottrell (2009) found that native Chinese readers exhibited a left-side bias in recognition, but not in novice Chinese learners, suggesting that the holistic processing might be reduced for native Chinese readers because they learn to facilitate character recognition by isolating the component of Chinese characters when the component could appear repetitively in other Chinese characters. Therefore, in our study, when participants failed to report the correct response, they might still be able to recognise the left side of the Chinese characters due to the facilitation of character recognition.

In summary, this experiment has demonstrated:

1. a contralateral preference in Chinese characters,

   and we also found

2. a sex effect where males performed better than females regarding the correctness of Chinese character recognition.

   The results of left-side bias in Chinese character recognition suggested that

3. RH obtained higher predicted values, especially in males.

4.3 Experiment 3: Contralateral and Ipsilateral Visual Pathways in SP-PS Chinese Characters Perception

In this experiment, we specifically looked into semantic- phonetic compounds to investigate if the positions of semantic or phonetic radicals would affect the preference of visual pathways and also the hemispheric effect. As we mentioned in the previous experiment, in Hsiao and Shillcock's (2005) study, they found gender differences when presenting SP and PS characters to male and female participants. Males tended to respond faster to SP than to PS, while females showed a non-significant difference in the opposite direction, suggesting a more bilateral activation. Moreover, many neuroimaging studies reported that during language tasks, females got more bilateral cortical activation than males (Baxter et al., 2003; Heinzel et al., 2013; Kansaku, Yamaura, & Kitazawa, 2000). For example, in a magnetoencephalography study in children, female children were reported to have more bilateral activity than male children, whose left frontal and temporal areas were more activated when performing a verb generation task (Yu et al., 2014). Therefore, to control for sex differences in lateralisation, we only recruited females because we wanted to investigate the contralateral-ipsilateral effects. We predict that when presenting characters to contralateral visual pathway will yield more correct results.

4.3.1 Method

Participants. Thirty female students from Taiwan, who were native Mandarin Chinese speakers, in the University of Edinburgh, volunteered to participate in the experiment, ranging in age from 19 to 33 (mean age= 24, SD= 3.1). All participants had normal or corrected-to-normal vision with no language disorders. Participants' handedness was also assessed using the EHI. One participant was reported as, and was rated as, left-handed while the others were right-handed.

Apparatus. The apparatus was the same as in Experiment 2.

Materials. 130 semantic-phonetic compounds characters were used from Hsiao and Shillcock's study (2006)(see Appendix D). The two types of characters are categorized by their structure: (1) 65 semantic-phonetic (SP) characters and (2) 65 characters PS characters. Strokes of each radical were assessed according to an online dictionary Han Dien, which included more than 70 thousand of both simplified and traditional characters (LONGWIKI, People's Republic of China, 2004). The frequencies of characters ranged from 0.25 per million to 386.35 per million according to the Chinese character frequency website (RIH-CUHK, 2001). The mean number of strokes of the characters was 12.04, with a minimum of 4 and a maximum of 25.

Design. The design was almost the same as Experiment 2. Two differences were that (1) there were two within-subject variables that were the ocular stimulation of characters (contralateral vs. ipsilateral) and the position of the radicals (SP vs. PS). (2) Because there were only 130 stimuli, there was only one session in this experiment.

Procedure. The procedure was also similar to Experiment 2. We found that participants were able to identify both 28 ms and 57 ms presentation speed; therefore, the presentation speed 14 ms was added as one of the presentation speeds in the experiment. Moreover, with fewer stimuli, the entire experiment would last for about 20-25 minutes.

4.3.2 Results

Descriptive Statistics. The way of evaluating correct responses was the same as Experiment 2. There were missing data for one participant. There were 3770 trials in total. The mean score for accuracy across all participants is 2.6 (SD= 0.8). The mean score for contralateral condition is 2.5 (SD= 1.7); the mean score for ipsilateral condition is 2.6 (SD= 1.7). The mean score for SP characters is 2.5 (1.7) and for PS is 2.6 (1.7) (Table 4.7).

	Mean	sd	Median	Min.	Max.
Overall (s)	2.6	0.8	2.5	0	4
		Condition			
Contralateral (s)	2.5	1.7	4	0	4
Ipsilateral (s)	2.6	1.7	4	0	4
		Radical Order			
SP	2.5	1.7	3	0	4
PS	2.6	1.7	4	0	4

Table 4.7: Descriptive Statistics of Scores for Different Variables.

Figure 4.7 shows the proportion of accuracy by condition, with ipsilateral condition (0.27) being slightly higher than contralateral condition (0.26).

In Figure 4.8, the proportion of accuracy in PS is higher than SP. In SP, the accuracy is 0.25, and in PS, the accuracy is 0.28.

There was a significant negative correlation between the score of correctness (mean = 2.6, sd = 1.7) and strokes (mean = 12.4, sd = 3.9) (r (128) = -0.4, $p < .001$), suggesting that participants read complex characters less well . There

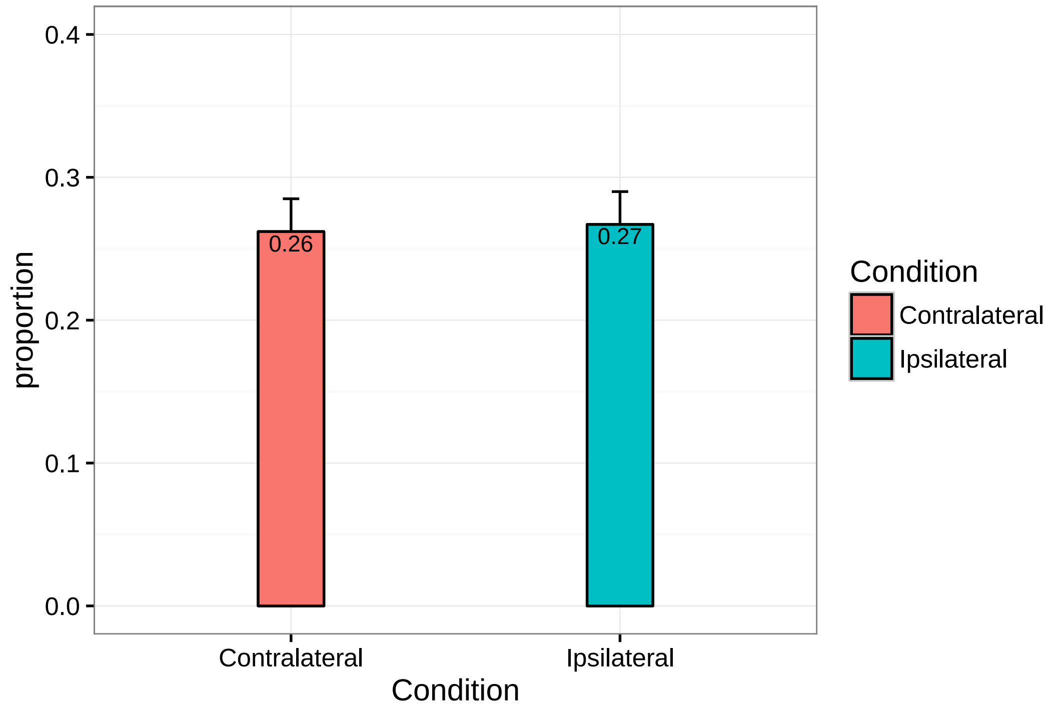

Figure 4.7: Proportions of Correct Response in Contralateral and Ipsilateral Condition.

was no significant correlation between the score of correctness (mean = 2.6, sd = 1.7) frequency (mean = 39.4, sd = 23.5) (r(128) = -0.1, *ns.*)

The Hemispheric Effect

We also looked into the hemispheric effect regarding SP-PS ordered characters. In Table 4.8, LH refers to the right visual field; RH refers to the left visual field. Therefore, the correct response of LH for an SP character is the phonetic radical, and for a PS character, the correct response would be a semantic radical (i.e. the radicals on the right side of the characters). On the contrary, the correct response of the RH for an SP character would be the semantic radical while the correct response for PS would be the phonetic radical. Overall, there were 851 trials. Table 4.8 only shows the proportions of LH and RH because there were very few BH cases (contralateral = 6, ipsilateral = 2 for SP; contralateral = 0, ipsilateral = 1 for PS). The numbers of correct responses in LH (558 trials) is more than in RH (284 trials); in other words, radicals presented to the right

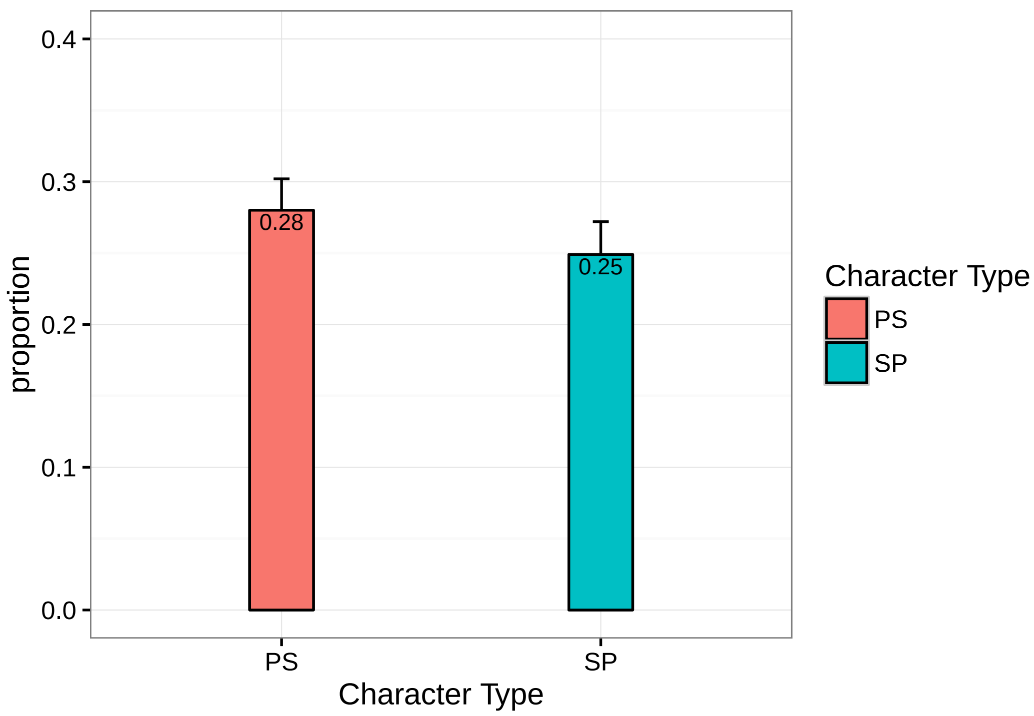

Figure 4.8: Proportions of Correct Response in SP and PS.

visual field obtained more numbers of correct responses than presented to the left visual field. In LH, there are more PS (27.6%) than SP (23.3%) in contralateral condition; more SP (27.1%) than PS (22.0%) in ipsilateral condition. In RH, SP is more than PS in both contralateral (SP: 26.4%, PS: 20.1%) and ipsilateral condition (SP: 35.5%, PS: 18.0%).

Linear Mixed Effects (LME) Analysis.

Probability of Correct Response

An LME analysis (Baayen, 2011; Bates & Maechler, 2013) is able to take account of variation within each subject and to attribute it more accurately to different independent variables. An LME analysis was carried out for the probability of correctness using a binomial scheme (Correct [YES or NO]). The random effect grouped by subject and stimuli. The fixed effects factors were the condition, sex, strokes, and frequency.

Condition	Contralateral		Ipsilateral		Total
Radical Order	SP	PS	SP	PS	
			LH		
Count (%)	130 (23.3%)	154 (27.6%)	151 (27.1%)	123 (22.0%)	558 (100%)
			RH		
Count (%)	75 (26.4%)	57 (20.1%)	101 (35.5%)	51 (18.0%)	284 (100%)
Total					842

Table 4.8: Proportions of Partially Correct Response Cases for Radicals by Hemisphere.

The results were similar to the results showed in Figure **??** . The condition was non-significant for SP characters, with the tendency of contralateral (50.1%) getting a slightly higher probability of correctness than ipsilateral (48.0%). The probability of PS (62%) getting correct responses was significantly higher than SP (48%) in ipsilateral condition. The probability of correctness in strokes was significantly lower with the increasing number of strokes. The frequency of characters was non-significant but showed a tendency for frequently seen characters to get more correct responses. (see Table 4.9).

The Hemispheric Effect

We also further analysed the hemispheric effects as we did in Experiment 2 by running an LME analysis. As in Experiment 2, the dependent variable was the partial correctness using Poisson distribution, and we also multiplied the dependent variable by 10 to prevent non-integers and to ensure that Poisson models worked well. The fixed effects factors were the condition, SP-PS, hemisphere (LH/ RH), strokes, and frequency (see Table 4.10).

There was no significance between contralateral/ipsilateral conditions across all related parameters. The predicted value of LH recognising SP characters in contralateral condition (2.96) was significantly lower than LH recognising

Fixed effects:

	Model Prediction	Std. Error	z value	Predicted 1*
intercept*	-0.08	0.25	-0.32	48.0%
Contralateral	0.08	0.11	0.79 *ns.*	50.1%
PS	0.49	0.13	3.68 ***	62.1%
Strokes	-0.07	0.01	-4.83 ***	46.3%
log(Frequency)	0.02	0.06	0.40 *ns.*	48.5%
Contralateral: PS	-0.27	0.15	-1.77 .	55.6%

Predicted 1*: Predicted Probability

intercept* : Ipsilateral: SP; Strokes; log(Frequency)

Significance levels: "." $<$ 0.1; "*" $<$ 0.05; "**" $<$ 0.01; "***" $<$ 0.001

Random effects:

Groups	Name	Variance	Std.Dev.
Stimuli	(Intercept)	0.1929	0.4392
Subject	(Intercept)	1.6114	1.2694

Number of trials: 3770, groups: Stimuli, 130; Subject, 29

Table 4.9: LME analysis on Probability of getting correct responses for SP-PS characters.

PS characters in contralateral condition (intercept) (3.05). The predicted mean score for LH recognising PS characters in contralateral condition (intercept) (3.05) was significantly higher than RH recognising PS characters in contralateral condition (2.87). The results above suggested that when semantic radicals were presented to the LH, participants were more likely to give correct responses to semantic radicals. The result in strokes was non-significant, only a very slight tendency of getting a lower predicted mean score with more strokes. We also found that the predicted score of LH recognising PS characters in contralateral condition was higher than RH recognising SP characters in contralateral condition. This find suggested that when semantic radicals were presented to different hemispheres, LH would be more likely to recognise the presented radical.

Fixed effects:

	Model Prediction	Std. Error	z value	Predicted 1*
intercept*	3.05	0.02	123.39 ***	3.05
Ipsilateral	-0.01	0.03	-0.49 *ns.*	3.04
SP	-0.09	0.03	-2.86 **	2.96
RH	-0.18	0.04	-4.49 ***	2.87
Ipsilateral: SP	-0.02	0.04	-0.56 *ns.*	2.95
Ipsilateral: RH	-0.02	0.06	-0.32 *ns.*	2.86
SP: RH	0.27	0.05	5.12 ***	3.05
Ipsilateral: SP: RH	0.10	0.07	1.35 *ns.*	3.1

Predicted 1*; Predicted Correctness

intercept*: Contralateral: PS: LH

Significance levels: "." $<$ 0.1; "*" $<$ 0.05; "**" $<$ 0.01; "***" $<$ 0.001

Random effects:

Groups	Name	Variance	Std.Dev.
Stimuli	(Intercept)	0.01	0.09
Subject	(Intercept)	0.00	0.06

Number of trials: 842, groups: Stimuli, 130; Subject, 29

Table 4.10: LME analysis on Poisson in partially correct responses for SP-PS characters.

4.3.3 Discussion

The results showed no significant differences between contralateral and ipsilateral presentation; however, a significant effect in PS getting higher probability of recognition than SP. We recruited only female participants. In Hsiao and Shillcock's (2005) study, they reported gender differences when presenting SP and PS characters to male and female participants. Their finding shows that males responded faster in SP than PS because, the authors claimed, males relied on LH for phonological processing (the phonetic radicals of SP characters are on the right side, presenting to the LH according to foveal splitting), whereas females showed no significance, only with a tendency of PS getting slightly faster, indicating a more bilateral effect. However, we not only found that PS characters were preferred but also significantly better. We found the same results as we did in Experiment 2 in strokes. With more strokes, the accuracy became lower. Though there was a tendency of getting higher accuracy in higher frequency characters, the result was not significant.

In hemispheric effects, we found that when PS presented contralaterally, the LH obtained significantly higher predicted mean score compared with SP. LH got higher mean scores than RH when PS was presented contralaterally, suggesting that participants were better at recognising the semantic radical of the characters. We also found that when SP was presented contralaterally, the predicted score of RH was lower than PS presented contralaterally to the LH. This finding suggested that participants recognise semantic components better when it was presented to the LH. In a recent study, Ding et al. (2016) have explored brain atrophy of native Chinese speakers with semantic dementia. They have found 36 regions in the brain were atrophic. However, they further found that the gray matter of left fusiform gyrus and left parahippocampal gyrus have significant correlation with the semantic scores of patients with semantic dementia. This neuroanatomical study suggests that some regions of

LH can be important when processing semantics, explaining why people got higher scores when semantic radicals were projected to the LH.

In summary, this experiment has demonstrated:

1. that the preference of contralateral visual pathway is cancelled out if we present SP-PS characters when only female readers are tested.

   We also found

2. that when the semantic radical is projected to the LH, participants are able to recognise the semantic component better.

4.4 Experiment 4: Contralateral and Ipsilateral Visual Pathways in Two-Character Chinese Words Perception

In Tsai et al.'s study (2006), they investigated how neighborhood size would affect reading Chinese two-character words. Neighborhood size (NS) refers to the numbers of two-character words that share either the first character or the second character. They found that the first constituent character of a word (NS 1) influenced word reading more than the second constituent character (NS 2). Therefore, using a haploscope, we ask if this effect can still be found? Moreover, will the visual pathways still be differentially involved in two-character word recognition? In this current experiment, we use two-character Chinese words as stimuli to see if neighborhood size (Tsai et al., 2006) would affect participants' responses when stimuli are presented contralaterally (Figure 4.9) or ipsilaterally (Figure 4.10).

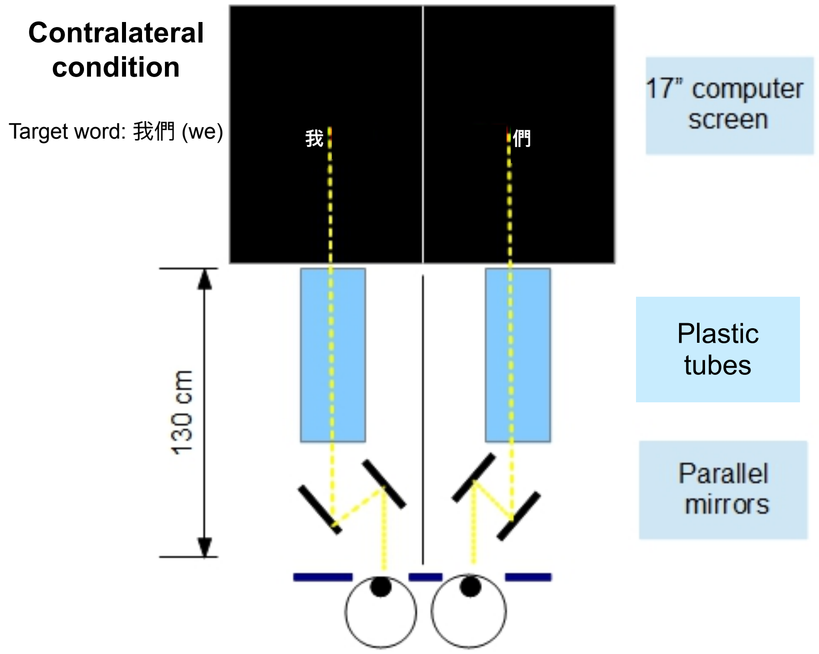

Figure 4.9: The diagram of two-character word presentation for Contralateral condition.

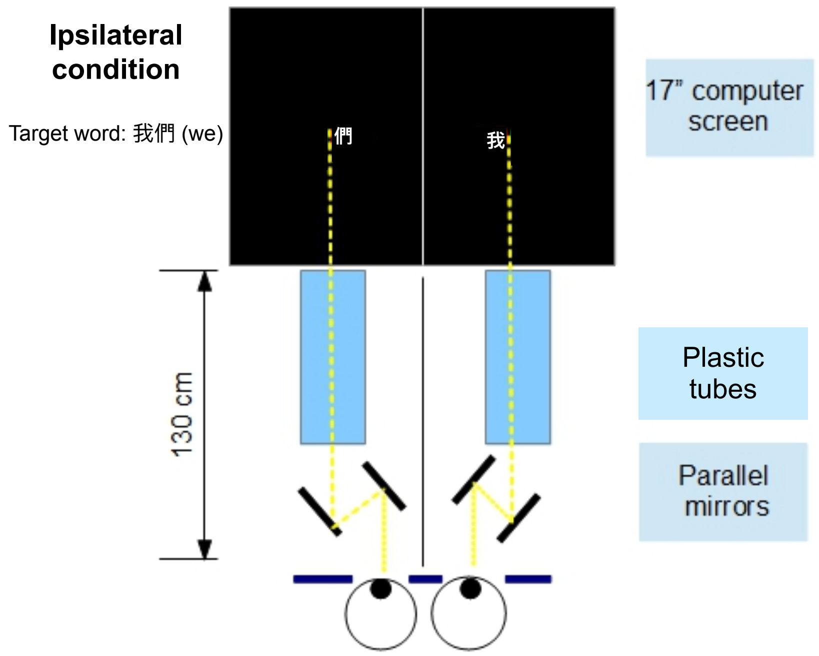

Figure 4.10: The diagram of two-character word presentation for Ipsilateral condition.

4.4.1 Method

Participants. Thirty (15 females) Taiwanese students, who were native Mandarin Chinese speakers, from the University of Edinburgh, received an honorarium for participating in the experiment, age ranging from 19 to 33 (mean age= 27, SD= 3.6). All participants had normal or corrected-to-normal vision with no language disorders. Participants' handedness was also assessed using the EHI. Three participants were reported and rated as left-handed while the others were right-handed.

Apparatus. The apparatus was the same as in Experiment 2.

Materials. 120 two-character Chinese words were chosen from the Chinese word frequency database which includes approximately 5 millions words (Academia Sinica, Taiwan, 2005)(see Appendix E). The stimuli are categorized into four groups by their neighborhood sizes (big x small) and frequencies (high x low). The neighborhood size was defined as the sum (NS) of characters sharing the first component (NS1) and the second component (NS2) (Huang et al., 2006) characters. The big neighborhood size was over 80, and the small neighborhood size was less than 16. The high-frequency words were over 125 per 5 million, and less than 15 per 5 million for low-frequency words.

Design. The design is almost the same as Experiment 3. One difference was that there were two within-subject variables, which were the ocular stimulation of characters (contralateral vs. ipsilateral) and neighborhood size.

Procedure. The procedure was the same as Experiment 2.

4.4.2 Results

Correct Response Evaluation. The way of evaluating correct responses was similar to Experiment 2 and 3. The difference was that, in this experiment, we used words as stimuli instead of characters. The score of a correct response is

4. Participants who failed to report the two-character words got 0. They got 1 if they correctly reported one of the two characters from the target word. If participants reported partially correctly from both characters, the score would be 1.5, and score 2 for correct response of one character. If one character was reported correctly and the other character reported partially correct, the score would be 3 (See Table 4.11).

Example Target	Participant Report	Left Constituent	Right Constituent	Score
對白(dialog)	Fail to report	Incorrect	Incorrect	0
	太陽	Incorrect	Incorrect	
	射水	Partially Correct	Incorrect	1
	晚日	Incorrect	Partially Correct	
	射日	Partially Correct	Partially Correct	1.5
	對	Correct	Incorrect	2
	白	Incorrect	Correct	
	射白	Partially Correct	Correct	3
	對日	Correct	Partially Correct	
	對白	Correct	Correct	4

Table 4.11: Example of measurement of all conditions of response for Chinese words.

Descriptive Statistics. There were 3600 trials in total. The mean score of accuracy was 2.5 (SD= 1.6). The mean score of left character was 1.2 (SD= 1); the mean score of right character was 1.3 (SD= 0.9). Table 4.12 shows the descriptive statistics for scores in condition (contralateral vs. ipsilateral) and sex (male vs. female). The mean score for accuracy across all participants is 2.6 (SD= 0.8). The mean score for contralateral condition is 2.5 (SD= 1.6); the mean score for ipsilateral condition is 2.5 (SD= 1.6). The mean score for male is 2.4 (1.7) and for female is 2.6 (1.6).

	Mean	sd	Median	Min.	Max.
Overall (s)	2.5	1.6	3	0	4
		Condition			
Contralateral (s)	2.5	1.6	3	0	4
Ipsilateral (s)	2.5	1.6	3	0	4
		Sex			
Male	2.4	1.7	2	0	4
Female	2.6	1.6	4	0	4

Table 4.12: Descriptive Statistics of Scores for Different Variables.

The accuracy is shown in Figure 4.11. The accuracy in the contralateral condition was 0.25, and in ipsilateral condition, the accuracy was 0.24.

Figure 4.12 showed the proportion of correct response by gender. Females (0.25) got more numbers of correct responses than males (0.23).

The Hemispheric Effect

We looked into the hemispheric effect regarding sex. In Table 4.13, as previously stated, LH refers to the right visual field; RH refers to the left visual field, and only shows the proportions of LH and RH because there were very few BH cases (contralateral = 1, ipsilateral = 3 for females; contralateral = 2, ipsilateral = 3 for males). The correct response of LH to a word is the character on the right side, and vice versa. There were more numbers of correct responses in LH than in RH for both males (318 trials in LH; 183 trials in RH) and females (353 trials in LH; 207 trials in RH); in other words, characters presented to the right visual field obtained more correct response than characters presented to the left visual field. In LH, males obtained more correct responses than females in the contralateral condition (52.2% for males; 42.5% for females) whereas females got more correct responses than males in the ipsilateral condition (47.8% for males; 57.5% for females). In RH, there were more correct responses in fe-

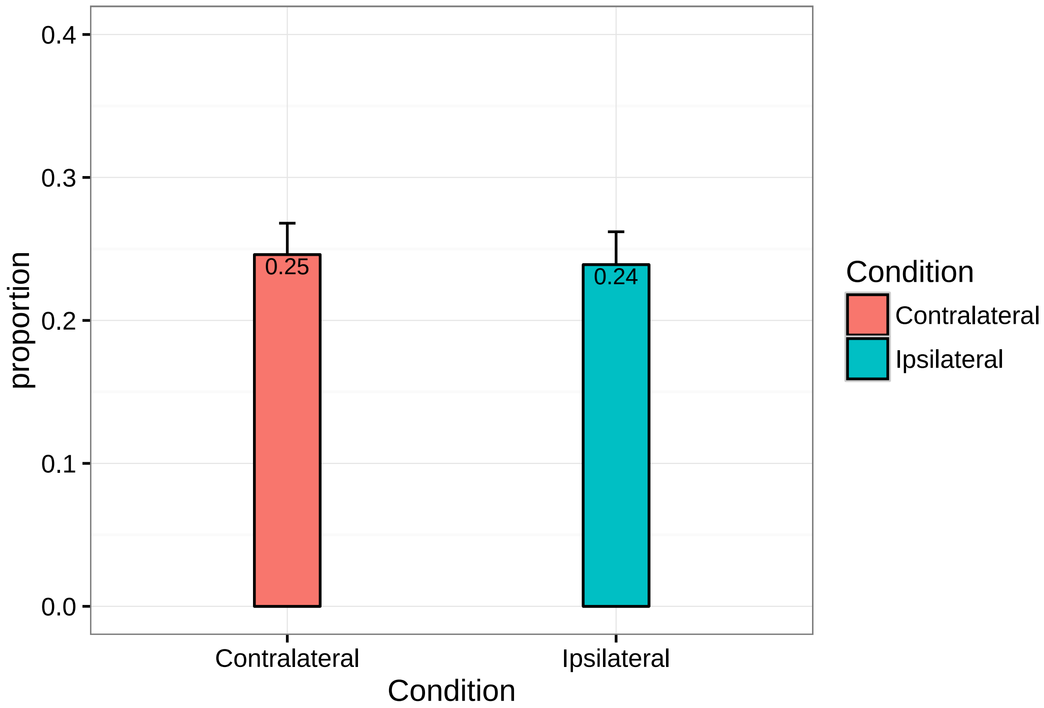

Figure 4.11: Proportion of Correct Response in Contralateral and Ipsilateral Condition.

males than males in the contralateral condition (51.9% for males; 60.4% for females). In the ipsilateral condition, males obtained more correct cases than females (48.1% for males; 39.6% for females).

Linear Mixed Effects (LME) Analysis.

Probability of Correct Response

We ran a number of LME analyses (Baayen, 2009; Bates & Maechler, 2009) that would be able to take account of variation within each subject and to attribute it more accurately to different independent variables. A LME analysis was carried out for the probability of correct responding using a binomial scheme (Correct [YES or NO]). The random effect was grouped by subject and stimuli. The fixed effects predicators were sex, condition, strokes, and frequency.

The effect of sex was non-significant, with the tendency of females (intercept) (50.2%) getting slightly higher probability of correctness than males

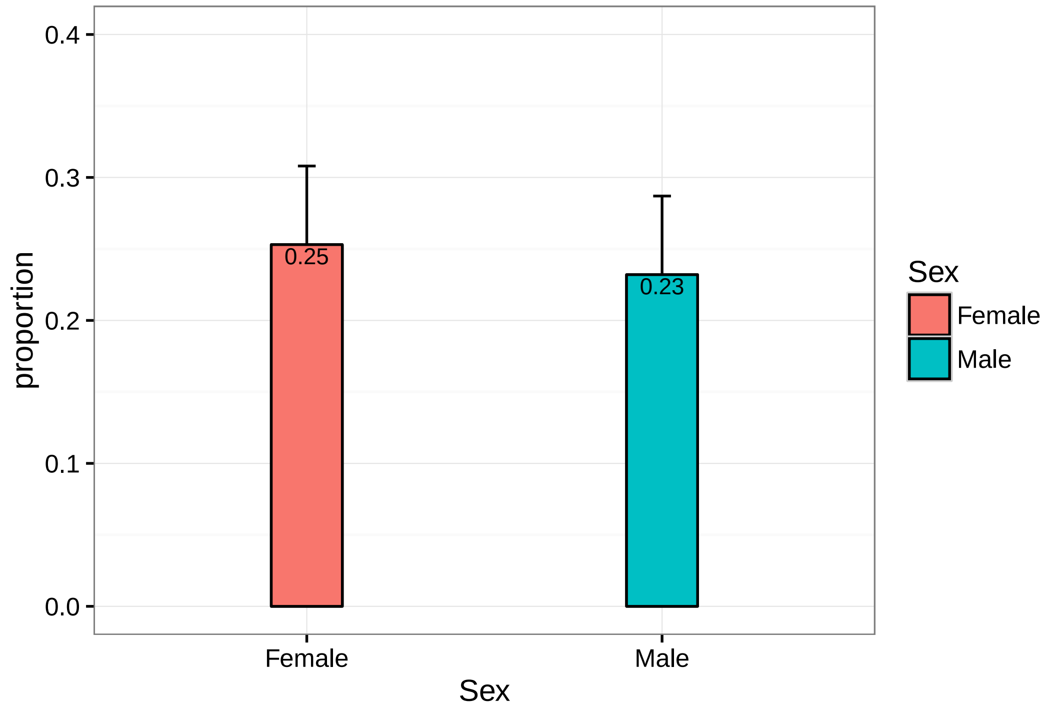

Figure 4.12: Proportion of Accuracy in Females and Males.

(41.8%) in the contralateral condition. The probability of the contralateral condition (50.2%) getting correct response was significantly higher than the ipsilateral condition (44.5%) in females. The probability of correct responses in strokes was significantly lower with an increase in the number of strokes. The effect of the frequency of words was significant and showed a tendency that with more frequently seen words, there was a higher probability of getting a correct response. (see Table 4.14). The probability difference between sex and condition only showed marginal significance.

The Hemispheric Effect

We further analysed the hemispheric effects as we did in Experiment 2 and 3 by running a LME analysis. As in the previous experiments, the dependent variable was the partial correctness using a Poisson distribution and we also multiplied the dependent variable by 10 to allow for non-integers and to

Condition	Contralateral		Ipsilateral		Total
Sex	Male	Female	Male	Female	
			LH		
Count (%)	166 (24.7%)	152 (22.7%)	150 (22.4%)	203 (30.3%)	671 (100%)
			RH		
Count (%)	95 (24.4%)	88 (22.6%)	125 (32.1%)	82 (21.0%)	390 (100%)
Total					1061

Table 4.13: Proportions of Partially Correct Response Cases for Radicals by Hemisphere.

ensure that Poisson models worked well. The fixed effects predicators were condition, hemisphere (LH/ RH), NS, strokes, and frequency (see Table 4.15).

There was no significant effect for condition and sex. The predicted value for LH with NS with big size was significantly higher than RH with big NS size (Hemisphere effects, z = -3.22). The predicted value for NS with small size in LH was significantly lower than NS with large size in LH (NS effects, z = -4.14). The result in strokes was significant, with a tendency of getting lower predicted value with more strokes. The result in frequency was significant, with a tendency of getting lower predicted value with higher frequency. We found an interaction between RH and NS, suggesting that the difference of predicted value for NS (big/small) sizes in LH was significantly higher than in RH (Hemisphere * NS effects, z = 2.61).

4.4.3 Discussion

Our results in two-character word recognition also demonstrated the contralateral visual pathway preference as we did in the single character experiment (Experiment 2). Therefore, we have proved that even when perceiving more

Fixed effects:

	Model Prediction	Std. Error	z value	Predicted 1*
intercept*	0.01	0.42	0.02	50.2%
Ipsilateral	-0.23	0.12	-1.99 *	44.5%
Male	-0.34	0.57	-0.60 *ns.*	41.8%
NS small	0.04	0.17 *ns.*	0.26	51.3%
Strokes	-0.03	0.01	-2.21 *	49.4%
log(Frequency)	0.29	0.04	7.28 ***	57.5%
Male: Ipsilateral	0.31	0.17	1.87 .	43.8%

Significance levels: "." $<$ 0.1; "*" $<$ 0.05; "**" $<$ 0.01; "***" $<$ 0.001

Predicted 1*: Predicted Probability

Intercept*: Female: Contralateral; NS big; Strokes; log(Frequency)

Random effects:

Groups	Name	Variance	Std.Dev.
Stimuli	(Intercept)	0.66	0.81
Subject	(Intercept)	2.34	1.53

Number of trials: 3600, groups: Stimuli, 120; Subject, 30

Table 4.14: LME analysis on Probability of getting correct responses for two-character words.

visual complex stimuli, that is, Chinese words, the contralateral visual pathway is still preferred. We once again demonstrated the contralateral preference in foveal processing from retinal to cortical processing, successfully extending Obregón and Shillcock's (2012) finding of a contralateral preference in perceiving English, by using Chinese stimuli with more visual complexity. However, in this experiment, we did not find sex differences, only a tendency of males having low probability of getting correct responses. Unlike single Chinese characters that are considered a salient perceptual unit (Tan et al., 2000), two-character words contain two separate characters and the identification has been found to involve higher level processing sustaining a constituent analysis and assembly process (Tan & Perfetti, 1999). Our finding that Chinese words with more strokes produced less accuracy was also consistent with Wang, He, and Legge's (2014) study in Experiment 2.

The hemispheric effects showed no significance in condition, only with a tendency of the ipsilateral condition getting a non-significantly lower mean score than contralateral condition. We also found that the mean score of the RH was significantly lower than LH. Tan and Perfetti (1999) demonstrated that when processing two-character Chinese words, it involves a constituent analysis and assembly process, and that the left hemisphere is specialised as a temporal and sequential analyzer; therefore, processing two-character words should be more lateralised in the left hemisphere, causing the lower mean score in the RH.

We also found that the predicted value of words with smaller neighbourhood size was lower than words with larger neighbourhood size. Tsai et al.'s (2006) result found that with larger neighbourhood size, the response for lexical decision was faster, suggesting that the neighbouring words were partially activated and play supportive roles in the early stage of lexical processing. Our results also demonstrated similar results by showing that the predicted value of words with larger neighbourhood size tended to be higher when the word was recognised partially correct. The result of predicted value for strokes was also consistent with the probability of accuracy for strokes. It showed that with more strokes, the predicted value became lower.

We also found an interaction between hemisphere and neighbourhood size. That is, when participants failed to report a correct response, they were able to recognise the right character (LH) of the word if NS was big. On the other hand, participants recognised the character on the left side better if the NS was small. Huang et al. (2006) found it took longer time to read words with higher frequency neighbours than those without higher frequency neighbours. Their results indicated that the words with the same first constituent character would be activated in the early stage of word recognition and therefore lead to a greater competition. Thus, our results suggest that with smaller neighbourhood size, participants were able to recognise the first constituent character more correctly. As concluded in Huang et al.'s study, it is a lexical access rather than hemispheric specification. We believe that, at this stage, it is the language itself but not hemisphere that makes the hemispheric and neighbourhood size effects.

In summary, this experiment has demonstrated:

1. a contralateral preference presenting Chinese words.

   We also found that

2. visual complexity would influence Chinese word recognition as in Chinese character recognition and

3. the larger a neighbourhood size was, the better participants were able to recognise part of the words.

   However,

4. with smaller neighbourhood size, the first constituent character would be reported more correctly.

Fixed effects:

	Model Prediction	Std. Error	z value	Predicted 1*
intercept*	3.01	0.02	118.93	3.01
Ipsilateral	0.02	0.01	1.46 *ns.*	3.02
Male	-0.07	0.03	-0.28 *ns.*	2.94
RH	-0.07	0.02	-2.94 **	2.94
NS small	-0.11	0.03	-4.26 ***	2.90
Strokes	-0.00	0.00	-3.47 ***	3.01
log(Frequency)	-0.01	0.01	-2.28 *	3.00
RH: NS small	0.08	0.03	2.50 *	3.09

Significance levels: "." $<$ 0.1; "*" $<$ 0.05; "**" $<$ 0.01; "***" $<$ 0.001

Prediction 1*: Predicted Correctness

intercept: Contralateral; Female; LH: NS big

Radom effects:

Groups	Name	Variance	Std.Dev.
Stimuli	(Intercept)	0.01	0.09
Subject	(Intercept)	0.00	0.06

Number of trials: 1061, groups: Stimuli, 120; Subject, 30

Table 4.15: LME analysis on Poisson in partially correct responses for two-character words.

Chapter 5

The Role of the Two Eyes in Horizontal Vergence during reading in English and Chinese

5.1 Introduction

In previous chapters, we looked into character- or word-based recognition in Chinese orthography. However, in the real world, people do not only perceive single characters or words. We read in daily life. In this chapter, we are going to explore the Edinburgh Five-Language Reading Corpus and compare the differences between Chinese and English to investigate the role of eye movements within fixations. Compared with English, Chinese is visually more complex. Liversedge, Drieghe, Li, Yan, Bai, and Hyönä (2016) compared three languages (English, Chinese and Finnish) and showed that regardless of the linguistic and visual differences, some universal reading behaviours were found. The total sentence reading time across three languages were similar, suggesting that word counts, mean word frequency and length of words all had similar impact on the total time.

In many studies, researchers using non-reading tasks have found that the two eyes are not synchronised between static fixations (e.g. Cornell, Macdougall, Predebon, & Curthoys, 2003; Enright, 1998) and within fixations (e.g. Engbert & Kliegl, 2004; Martinez-Conde, Macknik, & Hubel, 2000, 2004; Martinez-Conde, 2007; Simon, Schulz, Rassow, & Haase, 1984; Spauschus, Marsden, Halliday, Rosenberg, & Brown, 1999; Thiel, Romano, Kurths, Rolfs, & Kliegl, 2008). Knowing that the behaivours of the two eyes are not just duplications of each other's efforts, in this chapter, we are going to explore binocular reading and try to understand how it might be adaptive for the two eyes. We are going to look at the role of the two eyes in vergence during reading.

When looking at objects at a greater distance, the eyes diverge; on the other hand, the two eyes converge when looking at nearer objects. The sights of the two eyes intersect at a point. The points with the same disparity draw a horopter. There are two types of horopter, the geometric horopter and the empirical horopter. The geometric horopater is a circle that includes the optical centres of the two eyes. Points on the 'empirical horopter' define corresponding points projecting on the two retinas. When the eyes are converging, the intersection point of two eyes becomes closer to the viewer, bringing the horopter closer to the eyes. When the eyes are diverging, the point becomes farther away from the eyes (Figure 5.1).

If an object is farther away from the viewer than the horopter, the retinal disparity is uncrossed. In order to fixate on the object, the viewer has to uncross (diverge) the eyes and the object will be brought closer to/onto the horopter. On the contrary, if the object is closer to the viewer than the horopter, the retinal disparity is crossed. To fixate on the object, the viewer has to cross (converge) the eyes (Figure 5.2).

In stereopsis, there is an area which is called Panum's fusion area which refers to an area where two eyes are allowed to fuse without diplopia (Howard,

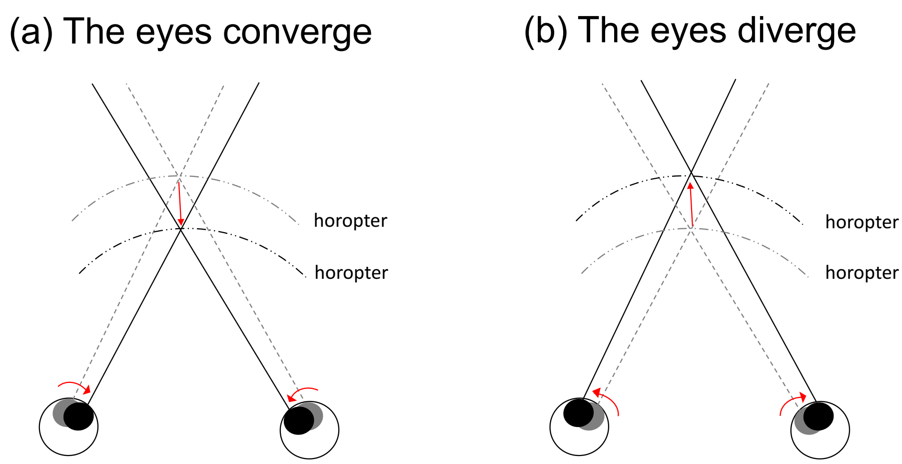

Figure 5.1: Schematic illustration of eyes converging and diverging.

2002). Westheimer (1979) reported that the psychological feature of stereopsis is related to relative disparity instead of absolute disparity. The absolute disparity refers to the angular difference of an eye from the fixation point to the corresponding point (i.e. the horopter); whereas the relative disparity, which is is more related to stereo-depth perception, is the difference between the two fixation points.

What is the relation between the terminology in optometry and research in reading eye movements? In reading eye movements research, a crossed fixation disparity refers to the situation where the right eye (RE) fixates on the text to the left of the left eye's (LE) fixation. An uncrossed fixation disparity, on the other hand, has the RE fixating on the text to the right of the LE's fixation (Liversedge, White, Findlay, & Rayner, 2006). Retinal disparity refers to binocular fusion, whereas fixation disparity (FD) refers to where the two eyes fixate simultaneously on the text.

When the FD is measured in pixels on the screen, an uncrossed (right eye fixation to the right of the left eye's) FD will be positive, and a crossed (right

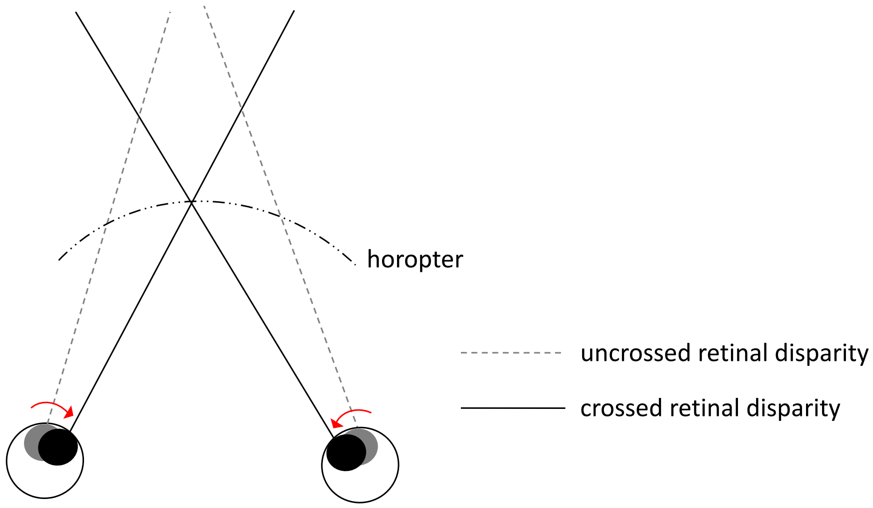

Figure 5.2: Schematic illustration of horopter.

eye's fixation to the left of the left eye's) FD will be negative. Both cases (uncrossed and crossed FDs) can involve divergence that brings the intersection of the sights of the two eyes farther away from the reader. In other words, no matter the FD is crossed or uncrossed, divergence will always move the FD in a more positive direction. On the contrary, convergence brings the intersecion of the sights of the two eyes closer to the reader, making a positive FD less positive or becoming negative, and a negative FD more negative. Therefore, the text on the screen can be in front of the horopter, on the horopter, or behind the horopter. These positions, in terms of reading eye movements research, correspond to uncrossed FDs, conjoint fixations, and crossed FDs, respectively.

It has been constantly reported that when using Eyelink technology, more crossed FDs are elicited, while more uncrossed FDs are elicited using Dual Purkinje technology. What causes the difference? Shillcock, Roberts, Kreiner and Obregón (2010) have theorized that the viewing condition of using Dual Purkinje technology is more challenging than the viewing condition of Eyelink techology. When using Dual Purkinje technology, subjects are required to read light texts on a dark screen in a dark room. On the other hand with Eyelink technology, subjects are asked to read dark texts on a light screen in a normal light room, making subjects be able to read easier (Table 5.1). In a more recent study, Kirkby, Blythe, Drieghe, Benson and Liversedge (2013) also compare two eye tracking technologies, SR Research EyeLink 1000 and the Fourward Technologies Inc. DPI binocular eye-tracking systems. Despite the fact that the disparity magnitudes are greater when using EyeLink system, the majority of fixations that were recorded using either technology were aligned. For unaligned fixations, using both technologies elicit a majority of uncrossed fixations. They suggest that experimental environment, such as luminance and viewing distance, affects the results. The studies above confirm that the viewing conditions do indeed underlie the crossed-uncrossed distributions of FDs generated by the two technologies.

Technology **Features**	Dual Purkinje	EyeLink
Room lighting	Dark	Normal lighting
Stimuli: background colour	Light	Dark
Stimuli: text colour	Dark	Light
Elicited FDs	More uncrossed	More crossed

Table 5.1: Comparison of the two technologies

Jones and Lee (1981) have proposed that the fusion of the input to the two eyes helps the visual information be processed better. By diverging or converging the sights of the two eyes, the text is brought onto the horopter, from which the text could be read easier. Below, we are going to observe and present differences in vergence behaviour. Studies have constantly shown that when same-size images (i.e. images at different distances, but have the same retinal subtended angle) of objects are presented as appearing farther away, the brain tends to process the images more accurately (Arnold & Schindel, 2010; Kersten & Murray, 2010). Kersten and Murray (2010) have reported that people read better when given two optician's charts of different sizes, presented at different distances with the same retinal angle: a 'big' one on the back wall of the room is read better than the other half size one, presented at half the distance of the room[1]. In Schindel and Arnold's (2010) study, they explored the visual sensitivity for objects presented in different angles (orientations) and in different illusory sizes. They found that people improved when the stimuli become *apparently* larger, through size constancy. Imaging research has demonstrated V1 mediation of illusory size perception (Murray, Boyaci, & Kersten, 2006; Fang, Boyaci, Kersten, & Murray, 2008): the spatial extent of activity in V1 increases with perceived, illusory size (Kersten & Murray, 2010).

From the above studies, we believe that the visual system is able to 'zoom in,' enriching the cortical resources given to the visual field. In this chapter, we apply the established research to reading. Whether the FD is crossed or uncrossed during reading fixations, the eyes are diverging to fixate a more distant object. Here, we only refer to the FD as becoming more positive or more negative, not "converging" or "diverging". If divergence occurs during reading, it indicates that the reader is inspecting something at more distance and more cortical resources should be applied. Though employing more cortical resource does not help the quality of the visual information entering the lenses, it can improve the granularity of the cortical substrate of the relevant visual processing. Compared with reading English and reading Chinese, it is more difficult for readers to distinguish between the basic elements of Chinese orthography compared with English orthography. The functional units of Chinese orthography are radicals (Chen, Allport, & Marshall, 1996), whereas the functional units of English are letters (Pelli, Burns, Farell & Moore-Page,

[1] The retinal angle is the same

2006). Since Chinese orthography is more complex visually, reading Chinese should be more visually demanding than reading English. The 'zooming effect' allows more cortical resources to the visual field and facilitates vision in non-reading tasks. Will this effect occur in the reading task? We now investigate the FD within fixations in English and Chinese, and report the similarities and differences between them.

5.2 Hypotheses

We tested the following hypotheses that:

1. *the majority of the fixations will be crossed.*

   Some studies (e.g., Jainta, Hoormann, Kloke, & Jaschinski, 2010; Nuthmann & Kliegl, 2009) have reported that the two eyes' fixations are predominantly crossed in most fixation data.

   And one novel prediction:

2. *there will be more divergence within fixations in the reading of Chinese than in the reading of English.*

   We looked for richer evidence of divergence than that captured by simple proportions of crossed and uncrossed FDs in reading the two orthographies. Instead we looked at movement within fixations. How a saccade turns into a fixation is itself a complex issue (we employed Eyelink's default definitions of fixation, below: fixations start at the end of a saccade and end at the beginning of a saccade). The absolute reduction of FD during the course of the fixation has generally been seen as adaptive in avoiding diplopia (Holmqvist et al., 2011, p. 24), and most studies reveal overall absolute reduction of FD during fixations (e.g. Blythe et al., 2006; Hendriks, 1996; Kirkby et al., 2013; Nuthmann & Kliegl, 2009), although such studies also all report a full range of convergent and divergent eye movements in fixations. Note that there is substantial tolerance for absolute disparity between the two retinal images (Erkelens & Collewijn, 1985; see, also Cornell et al., 2003, for the absence of diplopia accompanying FDs in natural viewing conditions).

5.3 Methodology

We analysed binocular eye-movements within fixations in the reading of English (24 pt monospaced Monaco font) and Chinese (PMingLiU, standard print), by 45 English and 46 Chinese native speakers. There were 22 newspaper stories in each language, containing about 5000 words, presented on consecutive pages of up to five lines, over some 500 lines. Maximum line length was 64 English characters. Participants fixated a small square below the right of the text, to see the next page. Reading direction for both languages was left to right, down the page. Each monospaced English letter was 14.4 pixels (0.43 degrees of visual angle), each Chinese character 28 pixels (0.85 degrees of visual angle).

Participants sat 75 cm from a 22″ Iiyama VisionMaster Pro 514 display. Screen resolution was 1024 x 768 pixels, page width 1000 pixels. Eye movements were recorded binocularly using an SR Research EyeLink II head- mounted video-based tracker. A chin-rest minimized participants' head movements. Each eye was calibrated independently by occluding the other eye with a black paper shade. After calibration, participants read two pages of on-screen instructions and then a practice article of four pages in length.

Before each page of black text on a white background was displayed, a black fixation disc 23 pixels in front of the first word of the first line was displayed for 1500 ms; participants fixated this disc until the page of text appeared. After reading the page, participants fixated on a 11 x 19 pixel rectangle below the end of the last line before pressing the keyboard to continue. Participants answered one yes-no comprehension question displayed after each story. Before proceeding with the next article, a grid of nine fixation targets was displayed in order that the experimenter could check calibration accuracy, and if necessary re-calibrate the instrument. The recording session was divided into three blocks with intervening rest-breaks, and lasted approximately 90 minutes. In each corpus, for this study we analysed only precisely temporally synchronized fixations by the left and right eye. They exclude most of the data that were outside the area of the text (approximately 3% of the data).

These fixations address binocular movement within a fixation, for a large, representative corpus of reading-for-meaning behaviours with multiline text in relatively typical reading conditions (normal room lighting; dark text on light background), with no other pre-processing of the data. Much Chinese text consists of two-place ('phonetic complex') characters, with one (typically semantic) radical on the left and one (typically phonetic) on the right, the whole character fitting within a square. In our stimuli, English letters (14.4 pixels; 0.43 degrees) and average Chinese radical size (14 pixels; 0.42 degrees) were closely similar in mean width, providing fortuitous scope for comparing reading in the two very different orthographies, even though the range of structural and semantic grains in the two languages naturally differ.

5.4 Results

We present the data for the English and Chinese corpora, and for their various subsets, and discuss them with respect to the hypotheses listed above.

The English corpus yielded 90,766 (48.4%) synchronized pairs of fixations out of a total of 373,700, such that the two eyes began fixating at precisely the same time and finished fixating at precisely the same time. The Chinese corpus yielded 98,367 (50.8%) out of 387,350.

There were two types of fixations: crossed and uncrossed. We calculated the RE and LE disparity by measuring the horizontal distance from the RE to the LE. For example, if the position of RE is 454 (13.8 degrees) pixel and the the position of LE is 432 (13.1 degrees) pixel, then the disparity will be 22 pixels (0.7 degrees) (RE-LE in pixels: 454-432 = 22; in visual angle: 13.8-13.1=0.7). A crossed fixation refers to the situation where the RE is on the left of the LE. An uncrossed fixation refers to the situation where the RE is on the right of the LE. A fixation was defined by the default of EyeLink II, and it refers to the period between the beginning of a saccade and the end of another saccade. The beginning of a fixation refers to the position in the beginning of the fixation, that is, the end of a saccade. The middle of a fixation refers to the position where the eye looked most frequently during a fixation. The end of a fixation was defined by the beginning of the following saccade.

1. *The majority of the fixations will be crossed.*

   In the English data, Table 5.2 shows a predominance of crossed fixations over those judged to be 'conjoint', in which the two eyes' fixation points were less than one character space apart (14.4 pixels; 0.43 degrees), and a very small proportion of uncrossed fixations. It is not feasible to compare the letters/words of English with the radicals/characters/words of Chinese in any principled way, but, as an approximate comparison, Table 5.2 shows the effects of adopting the same criterion for conjointness in Chinese as in English: i.e. 14.4 pixels (0.43 degrees) instead of the 28 pixels (0.85 degrees) for the width of a Chinese character. We see similar percentages of conjoint fixations in the two very different orthographies, but with slightly more uncrossed fixations in the Chinese data.

Disparity change inside fixations in English:

	Beginning	%	Midpoint	%	End	%
Crossed	75314	82.98%	75071	82.71%	73538	81.02%
Conjoint	14186	15.63%	14832	16.34%	16157	17.80%
Uncrossed	1266	1.39%	863	0.95%	1071	1.18%
Total	90766	100.00%	90766	100.00%	90766	100.00%

Disparity change inside fixations in Chinese,assuming 14.4 pixel (0.43 degrees) units approximately equivalent to radicals:

	Beginning	%	Midpoint	%	End	%
Crossed	79091	80.40%	76660	77.93%	74624	75.86%
Conjoint	14573	14.81%	16584	16.86%	17982	18.28%
Uncrossed	4703	4.78%	5123	5.21%	5761	5.86%
Total	98367	100.00%	98367	100.00%	98367	100.00%

Disparity change inside fixations in Chinese (28 pixel/0.85 degrees characters):

	Beginning	%	Midpoint	%	End	%
Crossed	66837	67.95%	63237	64.29%	60786	61.80%
Conjoint	29243	29.73%	32653	33.20%	34845	35.42%
Uncrossed	2287	2.32%	2477	2.52%	2736	2.78%
Total	98367	100.00%	98367	100.00%	98367	100.00%

Table 5.2: Fixation disparities in the synchronized subsets of the two corpora.

Shillcock et al. (2010) have claimed that one way in which fixation disparity is adaptive trades on the fact that uncrossed fixations are more robustly fused compared with crossed fixations. The best way of improving visual processing is by fusing the input to the two eyes. Schindel and Arnold's (2010) explored the visual sensitivity for objects presented in different angles (orientations) and in different illusory sizes. They found that people improved when the stimuli become *apparently* larger, through size constancy. Imaging research has demonstrated V1 mediation of illusory size perception (Murray, Boyaci, & Kersten, 2006; Fang, Boyaci, Kersten, & Murray, 2008): the spatial extent of activity in V1 increases with perceived, illusory size (Kersten & Murray, 2010). Thus we might have predicted that there should be more uncrossed fixations in the reading of the visually more complex Chinese orthography. The data provide little support for this prediction; a larger percentage of fixations are uncrossed in the Chinese corpus, but the difference is only a few percentage points.

Overall these data reflect the general fixation behaviours observed with Eyelink technology and the default reading conditions of normal room lighting and dark-on-light stimulus text (cf. Kirkby, Webster, Blythe, & Liversedge, 2008; Shillcock et al., 2010).

Figures 5.3 (a) and 5.3 (b) show the size of the horizontal and vertical fixation disparities at the beginning and end of the fixation, for the respective languages in pixels. The horizontal disparity is overwhelmingly skewed towards the negative, reflecting the "crossed" nature of most of the horizontal disparities. The same tendency is also shown in Figure 5.4 which illustrates the skewed horizontal disparity. We further look into the disparity for each participant. Figures 5.5 and 5.6 show the disparity before and after fixations for each participant in English. The individual differences are shown; however, we can see a robust effect of crossed disparity for all participants. The same effect is also found in Chinese (Figures 5.7 and 5.8).

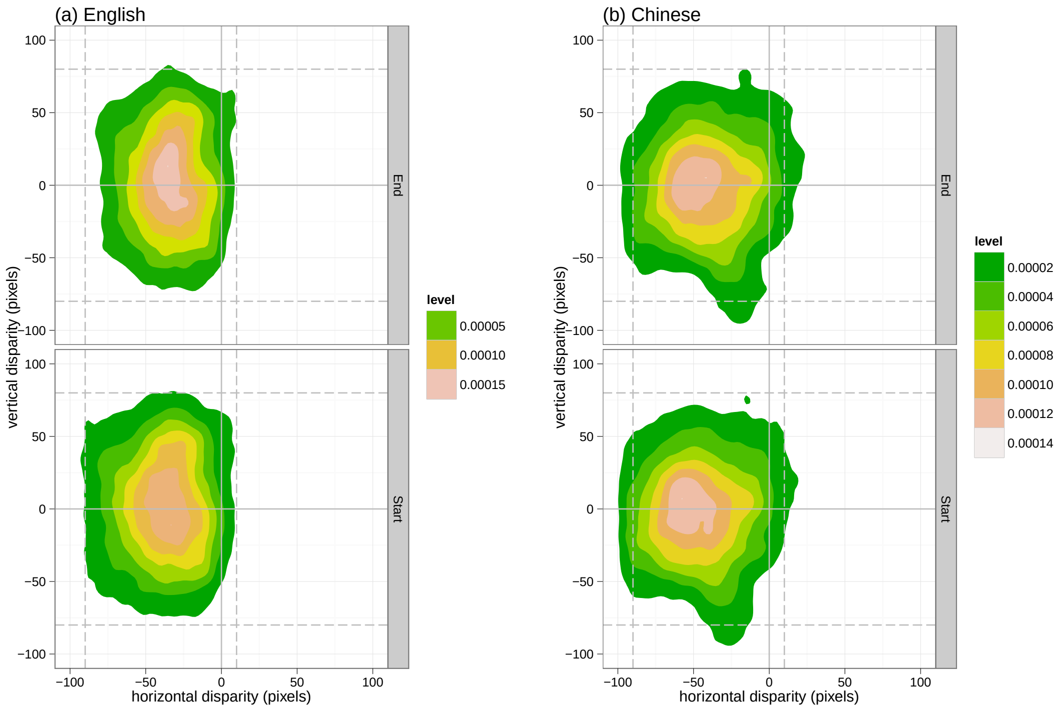

Figure 5.3: Disparity of English and Chinese data: before (upper) and after (lower) fixations.

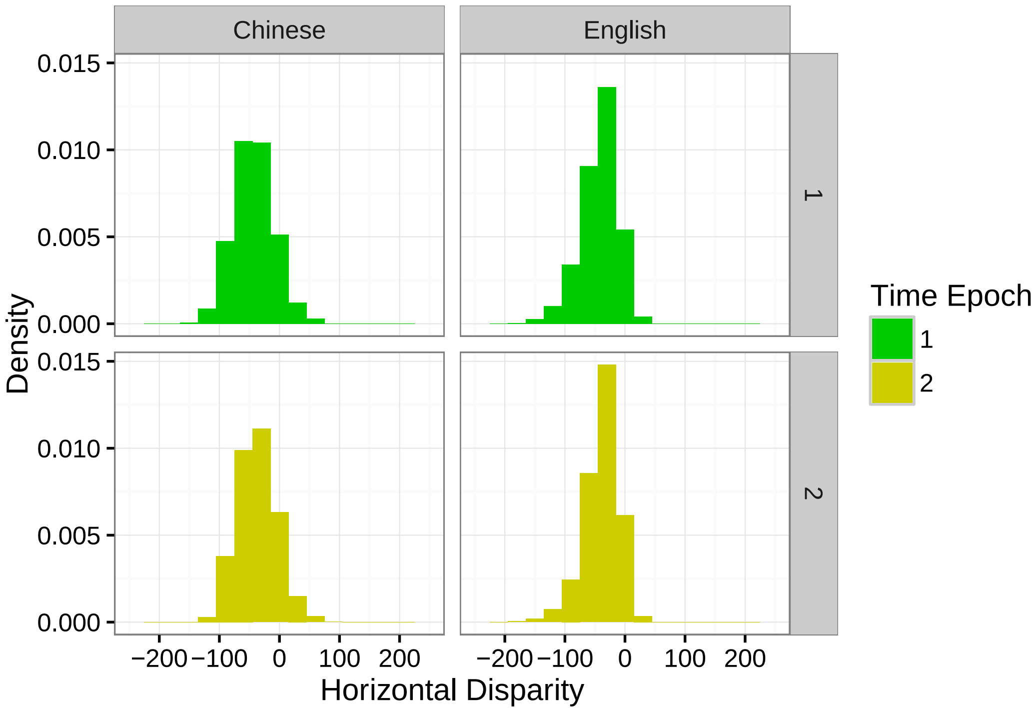

Figure 5.4: Density Plot of Horizontal Disparity for English and Chinese data: before (upper) and after (lower) fixations.

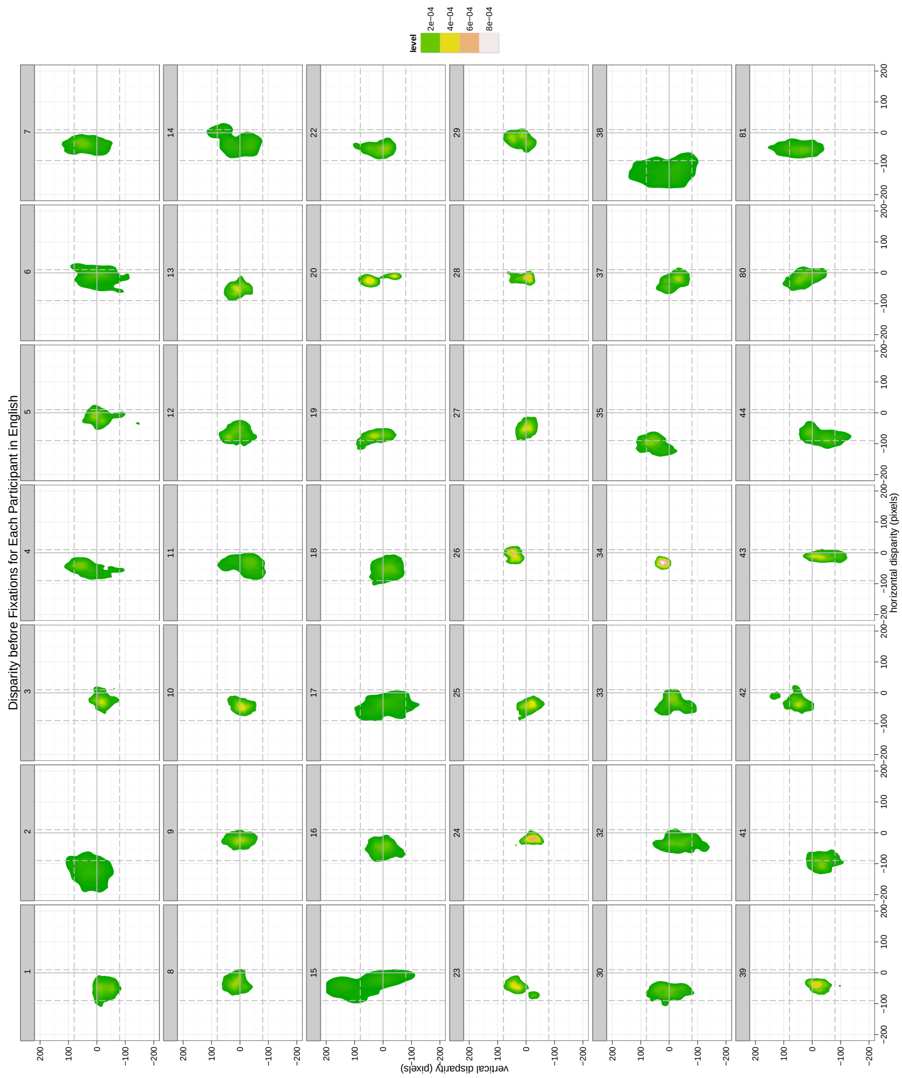

Figure 5.5: Disparity of English data for each participant: before fixations.

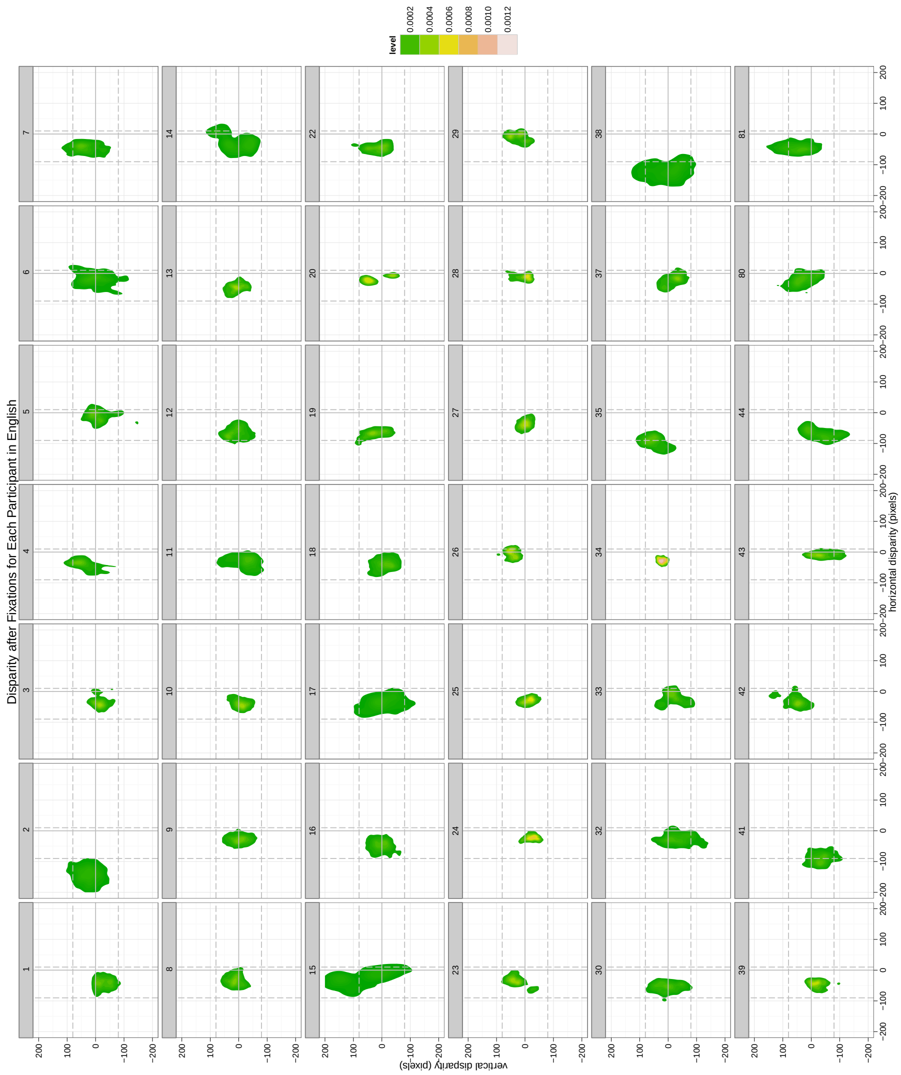

Figure 5.6: Disparity of English data for each participant: after fixations.

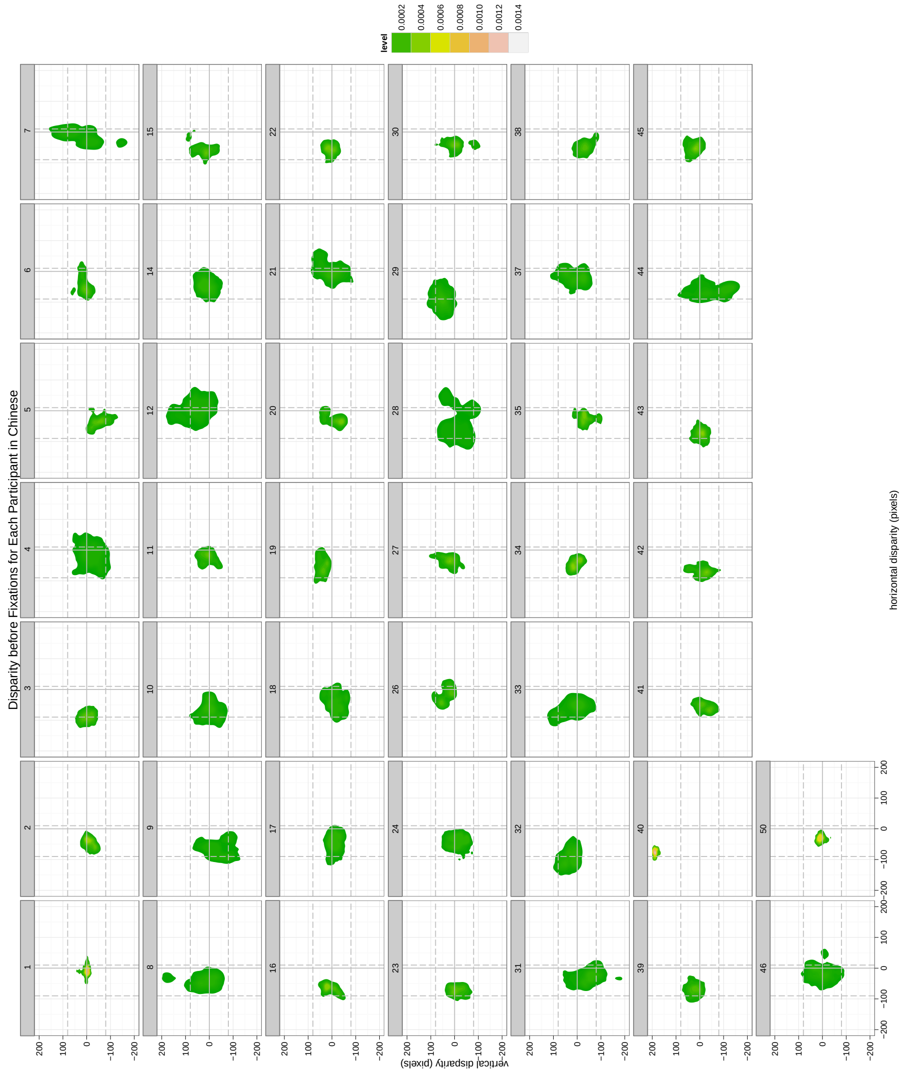

Figure 5.7: Disparity of Chinese data for each participant: before fixations.

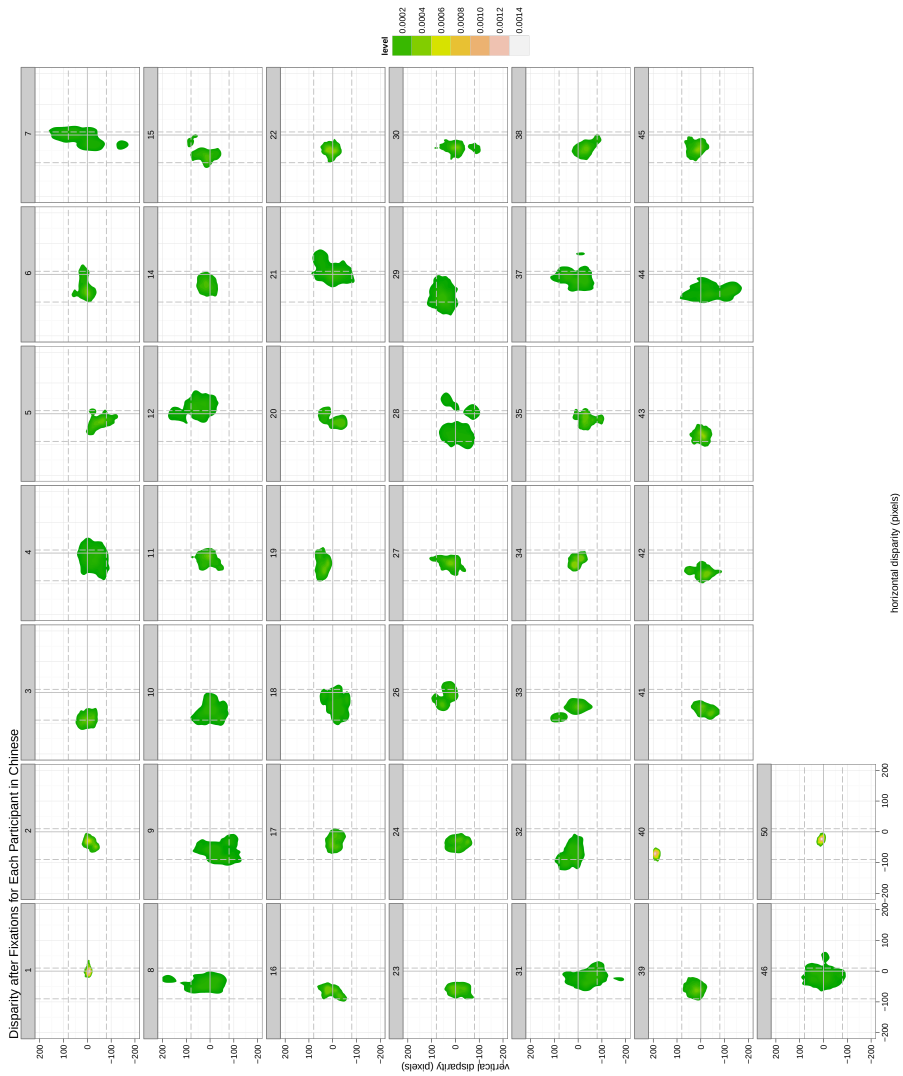

Figure 5.8: Disparity of Chinese data for each participant: after fixations.

2. *There will be more divergence within fixations in the reading of Chinese than in the reading of English.*

   Table 5.4 shows substantial majorities of crossed FDs in both orthographies at the beginning of fixation. These majorities fall in both cases, having turned into uncrossed FDs; this category change requires divergence of the eyes, and it is greatest in the Chinese data. (The small numbers of conjoint fixations involve identical pixel fixations by both eyes.)

   We ran linear-mixed effects models with four random predictors, a separate intercept fitted for participants, a separate intercept fitted for story, a separate intercept fitted for screen (i.e. page of the text), and a separate intercept fitted for reading line (on the screen) using the lmer programme in the lme4 (Bates, et al., 2013) package for R (R Core Team, 2012). In our linear mixed effects models, we added a new variable when creating a new model and compared models with and without the new variable. The variable was retained in the new model if the comparison between the two models was significant in a chi-squared test.

   We used FD as the dependent variable. The fixed factors were the Fixation Time Epoch (Beginning/End of fixation) and Language (Chinese/English) (Figure 5.9) (Table 5.3). The predicted FD for Chinese at the Beginning of Fixation was -1.3 degrees (-43.73 pixels) (i.e. a crossed FD); it changed in the positive direction by 0.2 degrees (5.89 pixels) at the End of Fixation, becoming less negative (EoF effects, $t = 46.06$). The predicted FD for English was smaller than Chinese by 0.1 degrees (3.07 pixels) (Language effects, $t = 21.42$). The Chinese FD changed more than the English FD by the End of Fixation (Epoch * Language effects, $t = -12.23$). These LME results are consistent with Tables 5.2 and 5.4.

Fixed effects:

	Model Estimate	Std. Error	*t* value	*Predicted 1	*Predicted 2
(Intercept)	-43.73	3.19	-15.56	-43.73	-1.3
EoF	5.89	0.13	46.06	-37.84	-1.1
English	3.07	0.30	17.85	-40.66	-1.2
EoF: English	-2.27	0.19	-12.23	-37.04	-1.1

*Predicted 1: Predicted disparity in pixels

*Predicted 2: Predicted disparity in degrees of visual angle

Random effects:

	Number	Variance	Std.Dev.
ID	46	296.29	17.21
Article	22	10.51	3.24
Screen Number	9	5.14	2.27
Line	5	13.12	3.62
Residual		723.75	27.07

Table 5.3: LME analysis of horizontal fixation disparities.

		Time Epoch	
	Language	BoF	EoF
Crossed	Chinese	88164	85754
	English	85634	85000
Conjoint	Chinese	56	61
	English	34	45
Uncrossed	Chinese	10147	12552
	English	5098	5721

Table 5.4: FDs changes between time epoch in English and Chinese.

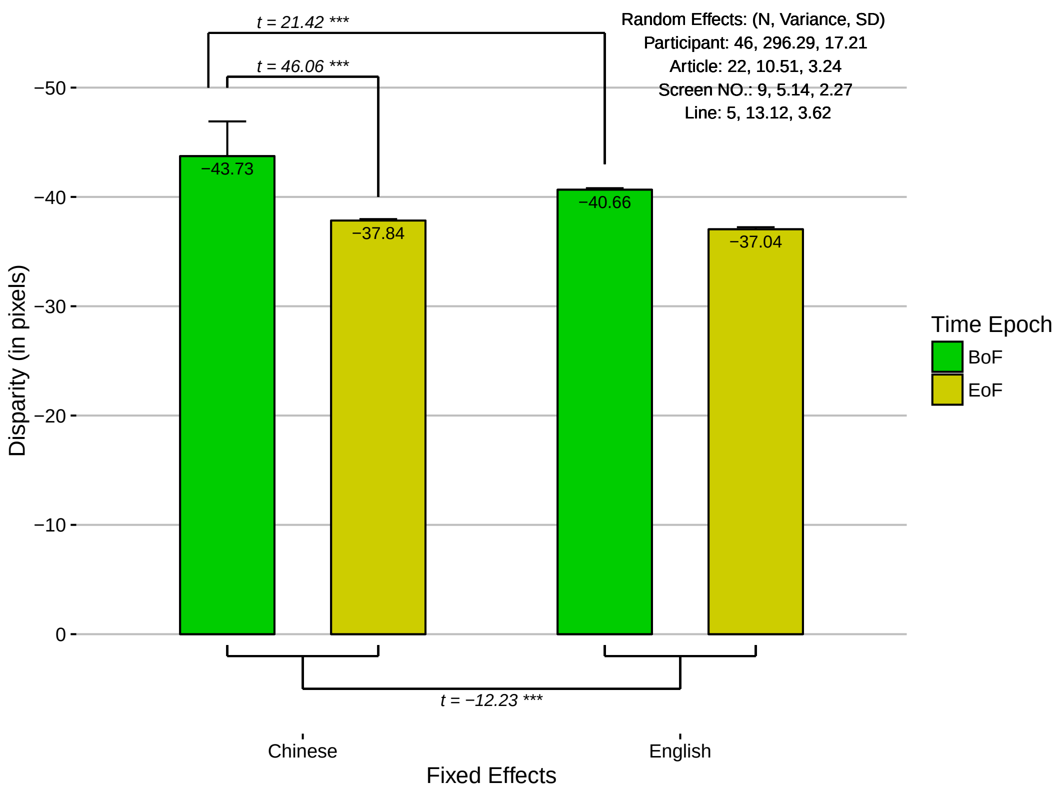

Figure 5.9: Plot of LME for FD for English and Chinese data: before and after fixations.

Is divergence greater in Chinese reading than in English reading simply because the Chinese fixations are longer and the eyes have more opportunity in Chinese reading to get where they are going? Figure 5.10 shows that the duration of Chinese fixations is slightly longer than that of English fixations. We conclude that Chinese readers do fixate for slightly longer. Note that the later stages in divergence produce a greater apparent distance effect, by reason of geometry. Our conclusion is that it is divergence that is critical in generating an illusion that the text is at a greater distance and should generate more of a size constancy effect, thereby devoting more cortical resource to the visual processing by expanding the cortical area being activated.

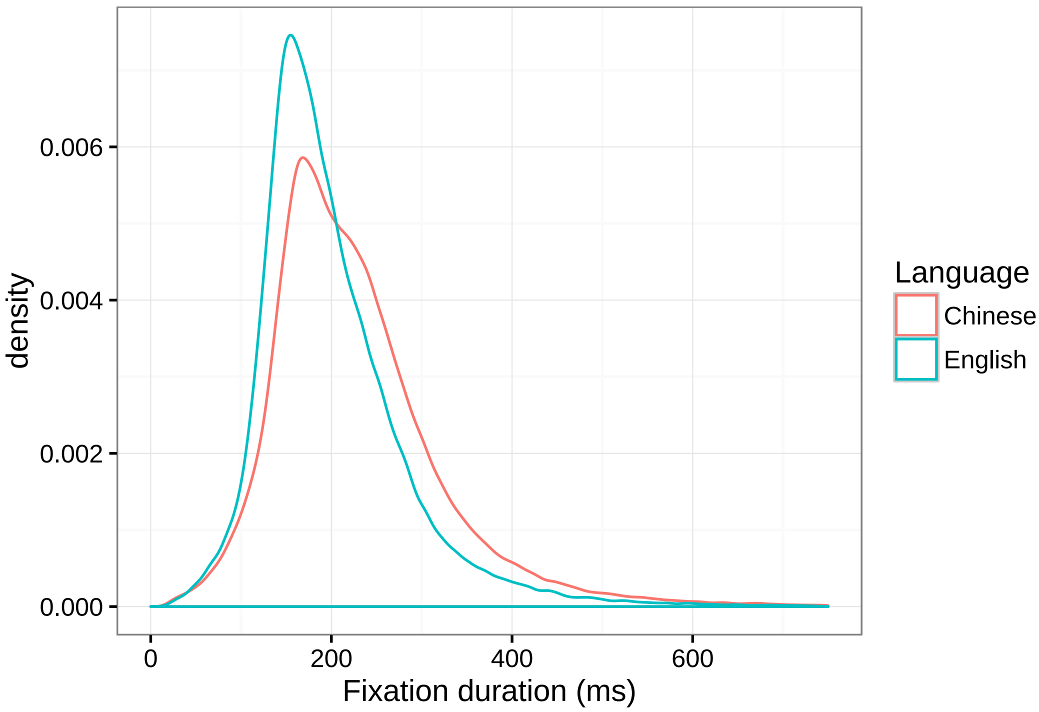

Figure 5.10: Plot of fixation duration for English and Chinese data.

5.5 Discussion

We have reported the details of the following summary observations that confirm existing studies:

1. there is substantial fixation disparity; overall, fixations were overwhelmingly crossed (RE to the left of the LE);

   The proportions of crossed and uncrossed FDs we report reflect the general fixation behaviours observed with the viewing conditions allowed by Eyelink technology, which involves reading in a normal room lighting and on dark-on-light text (cf. Kirkby et al., 2008; Shillcock et al., 2010). Using the same technology, it is predictable that there will be more crossed FDs than uncrossed ones.

2. changes in vergence angle during fixation in the reading of Chinese and English.

   Based on studies (Arnold & Schindel, 2010; Kersten & Murray, 2010) which have shown that people observe distant objects more accurately, we predicted that readers of Chinese orthography produced more divergence within fixations, whether the eyes are crossed or uncrossed fixation disparities (FDs); moreover, we found that Chinese readers changed FDs from crossed to uncrossed more than the readers of English orthography.

We theorize that this vergence behaviour is adaptive: When the reader reads visually complex text, they use the size constancy mechanism to 'zoom in' cognitively. The divergence of the eyes sends the text farther away, and helps to increase the cortical resources available to the visual field. Moreover, the crossed FDs have turned into uncrossed FDs more in Chinese than in English; this crossover change requires greater divergence of the eyes. The finding of Chinese having more crossover FDs than English has added to our theory that the 'zoom in' effect occurs more when the reader reads more visually complex text.

In English, the proportion of temporally synchronized binocular fixations (48.4%) is similar to those in Chinese (50.8%). The similarity of proportion suggests a quantitative generalization across reading even very different orthographies. This observation adds to Liversedge et al.'s (2016) claims concerning cross-linguistic generalizations in reading. The precisely temporally synchronized binocular fixations provided us with specific, convenient subsets of the total corpora; these subsets were still core, representative samples of the corpora.

In conclusion, we found and confirmed that the 'zoom in' effect occurs during reading. The effect which facilitates making cortical resources available to the visual field helps readers to read easier. Corpus studies can complement ingenious, carefully designed and controlled factorial studies using eye-tracking technology. This twin-track, interacting approach is converging on rich, interesting phenomena in reading behaviour, and on similarities and differences across readers, across eye- tracking technologies, across tasks, across languages and across orthographies.

Chapter 6

The Role of the Two Eyes in Vertical Movements during reading in English and Chinese

6.1 Introduction

In the previous chapter, we looked into the horizontal vergence during reading in Chinese and English and found that the greater visual complexity of Chinese orthography has induced more eye divergence. In this chapter, we are going to explore the vertical disparities between the two eyes in Chinese and English.

In Chapter 4, we looked into the two horizontal visual pathways, contralateral and ipsilateral pathways, and found that the contralateral visual pathway is preferred when presenting Chinese characters and two-character words. Is there also distinct visual pathway with regard to vertical dimention? Two distinct pathways, the dorsal and the ventral pathways, usually occur to people's mind when speaking of cortical visual processing. The dorsal-ventral distinction has a long history in cognitive neuropsychology (e.g., Hickok, & Poeppel, 2004; Singh-Curry, & Husain, 2009), with the ventral route being associated with visual template matching and meaning, and the dorsal route being associated with spatial processing and executive action. The dorsal pathway projects to the parietal cortex whereas the ventral pathway projects to the temporal cortex. In previous neuroimaging studies, the ventral pathway has been found to be preferred in the recognition of objects and faces (e.g., Haxby et al., 2001; Ishai, Ungerleider, Martin, Schouten, & Haxby, 1999; Pietrini et al., 2004) and the dorsal pathway is responsible for spatial information processing (Merigan & Maunsell, 1993). In a recent study, Martinaud et al. (2015) reported a case of a 14-year-old girl who has been suffering from a developmental visual impairment. She was diagnosed with severe prosopagnosia and dyslexia; however, her motion perception and dorsal stream functions, such as grasping and reaching, were intact. Martinaud et al. (2015) suggested a dissociation between spared dorsal and impaired ventral visual pathways. Therefore, the ventral pathway should not only be specialized to the recognition of objects and faces, but also visual word recognition and reading.

However, some studies have suggested that the dorsal pathway should play an important role in visual word recognition and reading (e.g., Pammer, Hansen, Holliday, & Cornelissen, 2006). Hansen, Stein, Orde, Winter and Talcott (2001) presented moving and static stimuli to developmental dyslexics and controls, and they found that the dyslexic group was significantly poorer than the controls in moving displays but that there were no significant differences in perceiving static visual form. They suggested the difference might result from selective impairments in dorsal stream functions. More studies also indicated that impairments in dorsal functions might lead to poorer reading skills (Amitay, Ben-Yehudah, Banai, & Ahissar, 2002; Kinsey, Rose, Hansen, Richardson, & Stein, 2004; Pammer & Wheatley, 2001). It seems that more studies have reported the relationships between dorsal pathway and reading ability. The reason for Martinaud et al. (2015) reporting a seemingly different result might be that the subject had multiple impairments and the condition was more complex than simply being dyslexic.

Some studies in English word reading show that the dorsal pathway is responsive to letter-by-letter serial reading (e.g., Cohen et al., 2008) and the ventral pathway is responsive for parallel word recognition (e.g., Cohen et al., 2002). Sun et al. (2011) further suggested a greater reliance on ventral processing in reading Chinese characters than in English words. A recent study, on the other hand, found that the visual dorsal pathway is associated with reading skills in Chinese (Qian, Bi, Wang, Zhang, & Bi, 2016). The question of how the visual pathways play a role in reading seems to remain controversial. Therefore, in this chapter, we are going to look into the vertical movements within reading fixations to try to gain a clearer insight of the dorsal/ventral issues.

6.2 Hypotheses

We tested the following hypotheses that:

1. *Horizontal vergence movements will be larger than vertical vergence movements.*

   Jainta, Blythe, Nikolova, Jones and Liversedge (2015) (Figure 2) report substantially larger horizontal fixation disparities compared with vertical ones, for their English stimuli, although Nuthmann and Kliegl (2009) (Figure 3) report comparable distributions in the horizontal and vertical dimensions, for their German stimuli. We assume that our disparity data will resemble those of Jainta et al. for our English stimuli, but it is an empirical question as to how the Chinese data will behave.

2. *The eyes will be moving upwards within fixations.*

We hypothesize that if the dorsal-ventral distinction where the ventral route being associated with visual template matching and meaning, and the dorsal route being associated with spatial processing and executive action exists, then there should be an association between vertical movements and dorsal-ventral visual pathways. Moreover, it has been constantly reported that people tend to recognise upper part of orthography better not only in single word recognition (Blais et al., 2009; Chi, Yan, Meng, Zang, & Liversedge, 2015; Perea, Comesaña, & Soares, 2012; Perea, Comesaña, Soares, & Moret-Tatay, 2012) but also in real-world reading.

6.3 Methodology

The methodology is the same as Chapter 5.

6.4 Results

1. *Horizontal vergence movements will be larger than vergence movements.*

   We have already seen that the majority of fixations are crossed with regard to the horizontal disparity between the two fixation points, in the previous chapter. Figure 5.3 and Figure 5.4 have shown an overwhelmingly skewed distribution towards the negative, reflecting the crossed nature of most of the horizontal disparities. That there is no such strong skewing of the distribution around the origin for the vertical disparity (Figure 5.3), implies no potential overall advantage at the beginning of the fixation for any vertical dimension of the fixation disparity. However, at the end of the fixation, there is a qualitative change regarding the vertical dimension of the disparity, in that the centre of the probability mass has moved in the direction of the LE/RE's fixation point being above the RE/LE's. This movement within the fixation does suggest that there is something adaptive about travelling within the vertical dimension of the fixation disparity. Figure 5.3 (a) shows horizontal disparity plotted against vertical disparity for our English multiline data. The plots are approximately symmetrical, more closely resembling the data reported by Nuthmann and Kliegl (2009) than those reported by Jainta et al. Indeed, our English data show a more extended vertical distribution compared with the horizontal distribution. To some extent these data may reflect inherent differences between single-line and multi-line reading, and to some extent they will reflect the fact that eye-tracking is typically more reliable in the horizontal dimension, compared with the vertical. Nevertheless, these plots represent 90,766 different fixations and the movement between the beginning and end of the fixation is a reliable overall shift.

We ran linear-mixed effects models with four random predictors, a separate intercept fitted for participants, a separate intercept fitted for story, a separate intercept fitted for screen (page of the text), and a separate intercept fitted for reading line (on the screen) using the lmer programme in the lme4 (Bates, et al., 2013) package for R (R Core Team, 2012). In our linear mixed effects models, we added a new variable when creating a new model and compared models with and without the new variable. The variable was retained in the new model if the comparison between the two models was significant in a chi-squared test.

We used vertical fixation disparity (FD) as the dependent variable (regardless of whether LE is on top of RE or LE is on top of RE). The fixed factors were the Fixation Time Epoch (Beginning/End of fixation) and Language (Chinese/English) (Table 6.1). The predicted vertical FD for Chinese at the Beginning of Fixation was 1.0 degrees (33.08 pixels); it became smaller by 0.02 degrees (0.56 pixels) at the End of Fixation (EoF effects, t = -4.56). The predicted FD for English was larger than Chinese by 0.1 degrees (3.46 pixels) (Language effects, t = 25.30). The change between Chinese FD and the English FD by the End of Fixation was not significant (Epoch * Language effects, t = 0.73). This result suggests that the vertical disparity becomes smaller by the End of Fixation and the vertical disparity of English is significantly larger than Chinese. However, when looking at the Figures 5.9, we can see that the change of horizontal disparity is slightly larger than vertical disparity in regard to pixels.

Fixed effects:

	Estimate	Std. Error	*t* value	*Predicted 1	*Predicted 2
(Intercept)	33.08	1.79	18.46	33.08	1.0
EoF	-0.56	0.12	-4.56	32.52	0.9
English	3.46	0.14	25.30	36.54	1.1
EoF: English	0.13	0.18	0.73	36.11	1.0

*Predicted 1: Predicted disparity in pixels

*Predicted 2: Predicted disparity in degrees of visual angle

Random effects:

	Number	Variance	Std.Dev.
ID	46	118.61	10.89
Article	22	8.54	2.92
Screen Number	9	1.24	1.11
Line	5	0.45	0.67
Residual		670.10	25.89

Table 6.1: LME analysis of vertical fixation disparities

2. *The eyes will be moving upwards within fixations.*

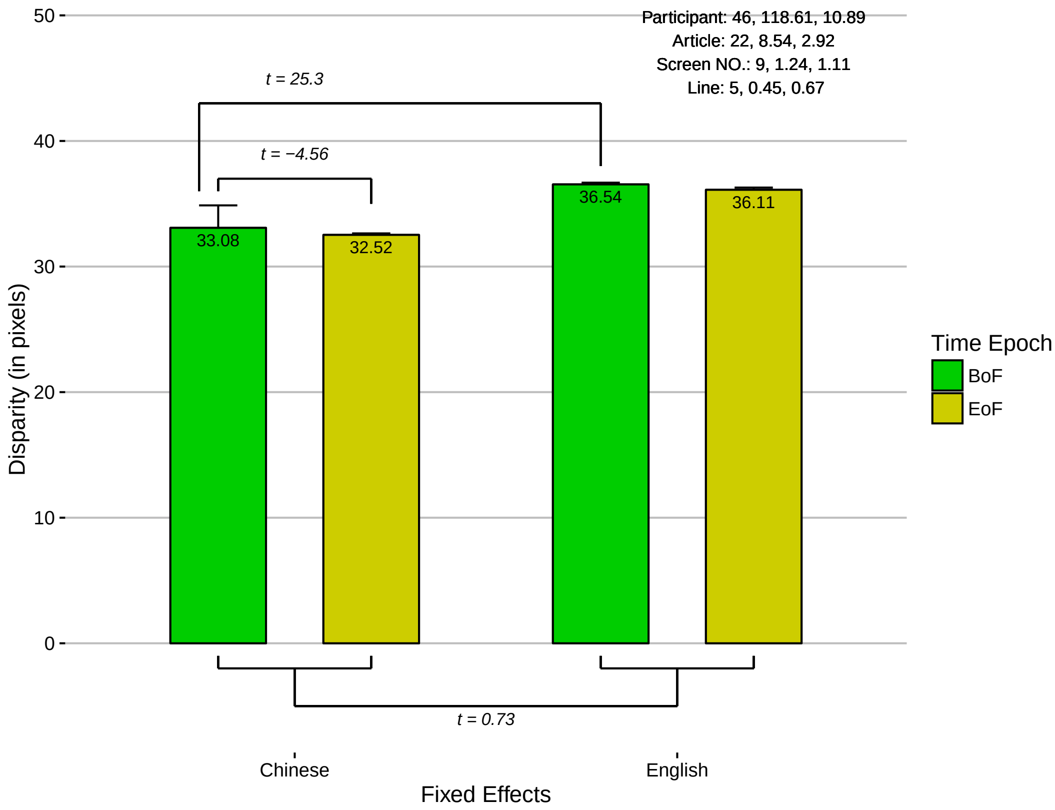

Figure 6.1: Plot of LME for vertical FD for English and Chinese data: before and after fixations.

Figures 6.2 (a) and 6.3 (a) show the total distance moved within the fixations by the RE and the LE for synchronized data, for English and Chinese respectively. They show comparable distributions for the two languages, in which the RE tends to move rightwards and the LE moves left and right in more equal proportions. The outer ring of the distributions, for both languages, indicates that for our multiline reading task, there are many instances of considerable movement within the fixation [1].

Moreover, Figures 6.2 and 6.3 both show a robust tendency towards vertical movement of both eyes across the whole fixation, for both eyes and for both languages. The implication is that the progress of each eye across

[1]These are relative movements measured within single fixations and cannot reflect, for instance, headpiece slippage in the Eyelink-2 apparatus.

the line of text is a sawtooth, such that the line of sight from the eye tends to fall with respect to the text during the saccade and then tends to climb during the fixation.

However, we leave this discussion of vertical disparity with the observation that this sawtooth pattern of saccades and fixations in reading may tend to place the fixated word initially in the upper visual field before moving it to the lower visual field towards the end of fixation. There is no suggestion that the upper and lower visual fields are sharply divided in the way that has been claimed for the left and right visual fields, but the literature does contain claims for a lexical/priming processing advantage for the upper visual field (Goldstein & Babkoff, 2001). The dorsal-ventral distinction has a long history in cognitive neuropsychology (e.g., Hickok, & Poeppel, 2004; Singh-Curry, & Husain, 2009), with the ventral route being associated with visual template matching and meaning, and the dorsal route being associated with spatial processing and executive action. The upper visual field projects initially to the ventral pathway, and the lower visual field to the dorsal pathway (cf. Previc, 1990). We speculate here (in the absence of any other explanation of why this upwards movement might be adaptive) that it is appropriate for the earlier part of the fixation to be associated with visual recognition and for the later part of the fixation to be associated with executive action. The tendency to move upwards suggests that, not only in single word recognition (Blais et al., 2009; Chi, Yan, Meng, Zang, & Liversedge, 2015; Perea, Comesaña, & Soares, 2012; Perea, Comesaña, Soares, & Moret-Tatay, 2012) but also in real-world reading, the upper part of words/characters are more informative than the lower parts. The upper part of words tends to continue to project to the ventral pathway even after the eye has been moving upwards.

6.5 Discussion

Following the previous Chapter, we investigated the small movements that occurred inside the fixations of both eyes in English and Chinese text. We looked into the vertical disparity changes that occurred inside the fixations in closely comparable reading-for-understanding tasks involving 2000-word, multi-line, black-on-white, English and Chinese text. On principle, we have included all of the data, a grand total of 373,700 fixations in English and 387,350 fixations in Chinese; we have not cleaned up the data in any way, relying on large numbers to correct for any genuinely anomalous data that do not reflect reading behaviour. In the current study, we have not taken into account the precise registration with the words of the text; instead we have assumed that all of the data reflect reading behaviour.

We report a number of novel results and results that speak to more mixed reported data.

1. Vertical movements within a fixation tend to be smaller than horizontal ones.

2. Vertical movements within a fixation tend to be upwards.

As mentioned above, our data has shown horizontal disparity plotted against vertical disparity for English multiline data. The plots are approximately symmetrical, more closely resembling the data reported by Nuthmann and Kliegl (2009) than those reported by Jainta et al. (2015). Our data show a more even vertical distribution compared with the horizontal distribution, especially in English. To some extent these data reflect inherent differences between single-line and multi-line reading, and to some extent they reflect the fact that eye-tracking is typically more reliable in the horizontal dimension, compared with the vertical.

We speculate that the earlier part of the fixation is associated with visual recognition; whereas the later part of the fixation is associated with executive action. The tendency to move upwards suggests that, not only in single word recognition (Blais et al., 2009; Chi, Yan, Meng, Zang, & Liversedge, 2015; Perea, Comesaña, & Soares, 2012; Perea, Comesaña, Soares, & Moret-Tatay, 2012) but also in real-world reading, the upper part of words/characters are also informative; by moving upwards, the upper part of the word is available to the ventral pathway longer.

Why should there be movement at all, within a fixation? Martinez-Conde (2004) and others have suggested that the reader moves the eye over the visual world to prevent habituation occurring at the retina and elsewhere, leading to the familiar fading of the perceived image. We have shown that the movement within a fixation is not solely concerned with preventing fading, but is also adaptive from the perspective of adjusting the fixation disparity, preparing for the next saccade, perhaps negotiating the processing preferences of the ventral and dorsal pathways, and potentially responding to the very local informational structure of the fixated text.

In conclusion, we investigated eye movements within fixations with regards to the vertical dimension. We found that vertical disparity is smaller and more symmetric than horizontal ones and the eyes are moving more upwards within fixations which is in line with that the upper part of words/characters are informative even during reading.

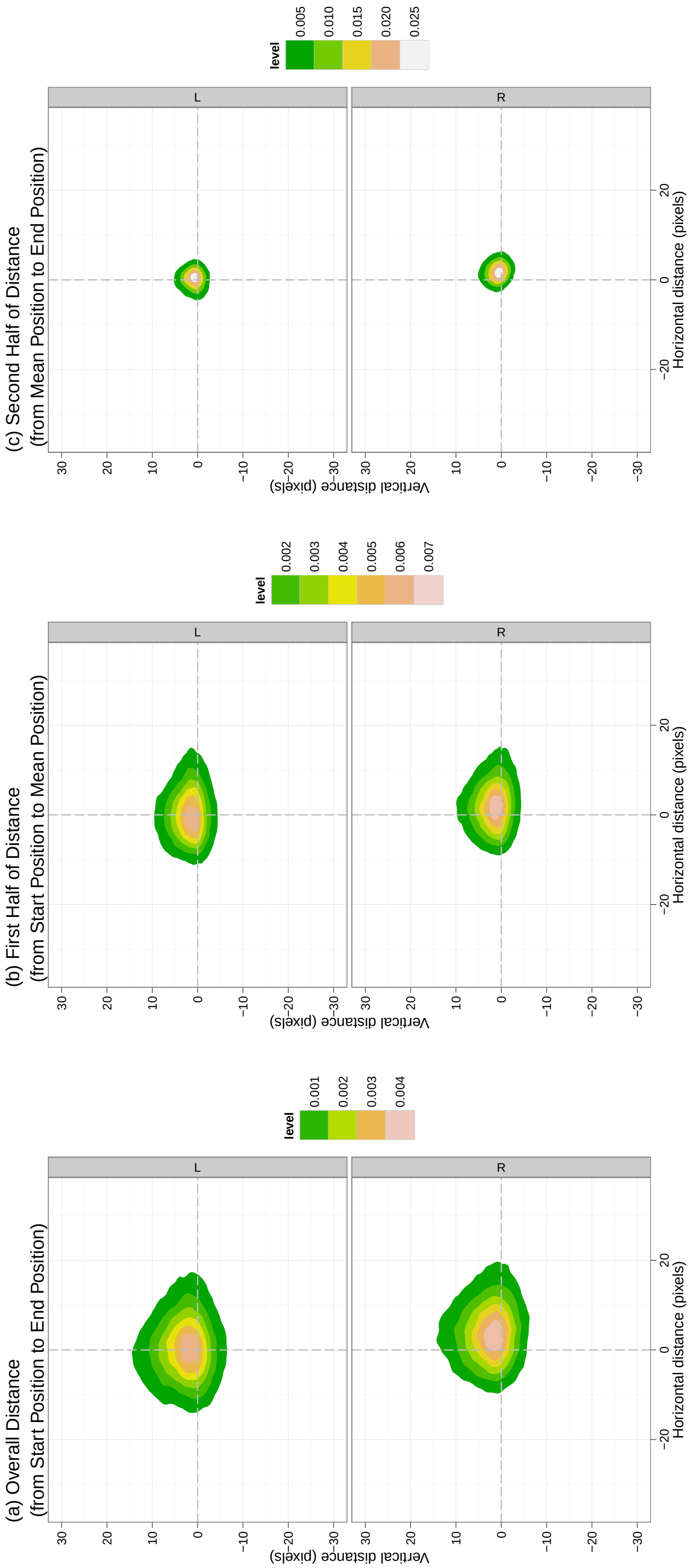

Figure 6.2: Distance in pixels that the two eyes travelled in the synchronized English data (105120 pairs of fixations).

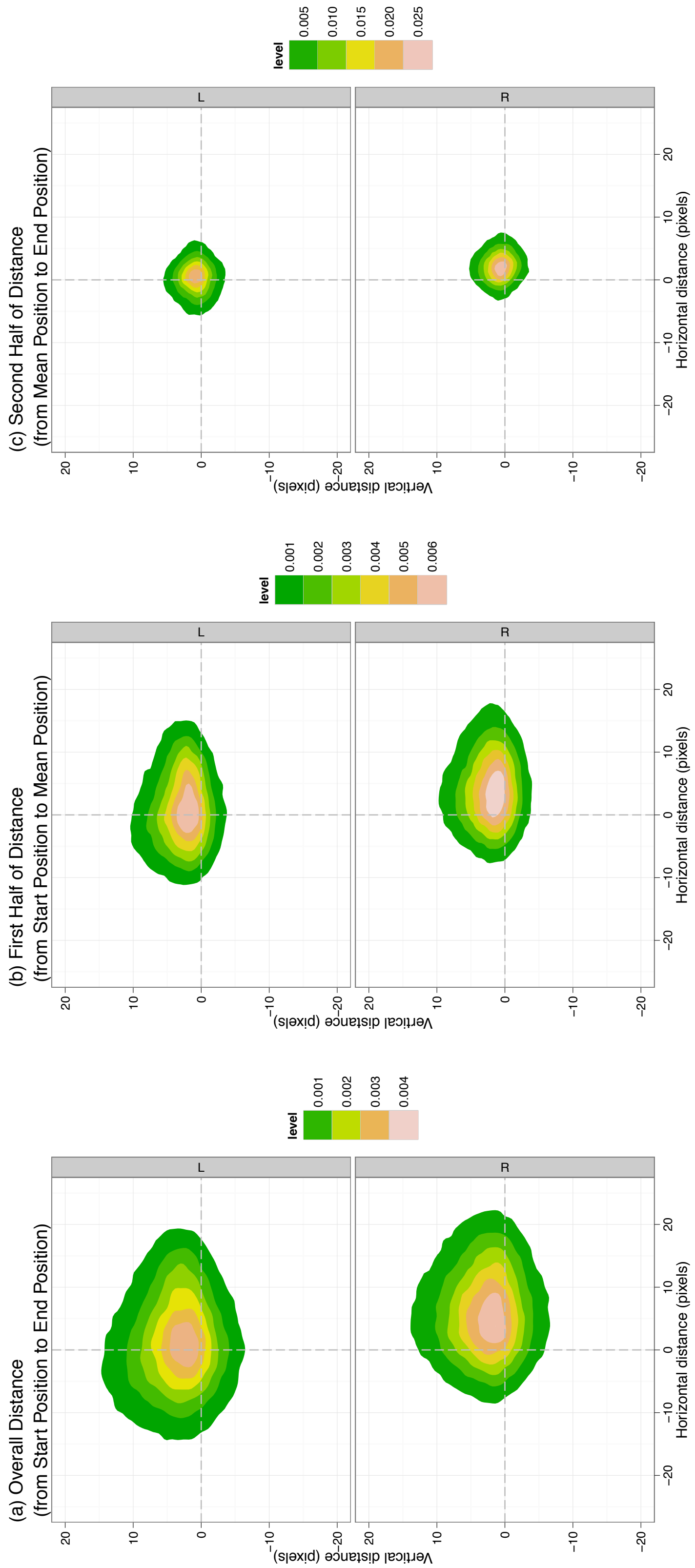

Figure 6.3: Distance in pixels that the two eyes travelled in the synchronized Chinese data (119770 pairs of fixations).

Chapter 7

Regressions after Return Sweeps in English and Chinese

7.1 Introduction

Continuing from the previous chapter, we still looked into the reading corpus. In this chapter, we investigated the physical effect, *return sweeps*, that occurs during multiline texts reading. In the early 20th century, Tinker and colleagues investigated the reading time of different text lengths or sizes (e.g., Paterson & Tinker, 1940, 1942, 1944, 1947; Tinker, 1958; Tinker & Paterson, 1946). They found that when the lines of text exceed a certain line length, the reading time would increase. Paterson and Tinker (1940) concluded that the increase of reading time was due to the corrective regressive saccades after return sweeps.

Sun, Morita, and Stark (1985) reported that the reading patterns of English and Chinese were similar; moreover, behaviours in the two languages were qualitatively similar if the eye is not located at the first character of the line after return sweeps. It is likely that the eyes are not properly located after long saccades (ie. return sweeps), causing the eyes to make corrective saccades (Just & Carpenter, 1980).

In a later study, Hofmeister, Heller and Radach (1999) conducted two experiments. In the first experiment, they presented texts with different line lengths and reported that the number of corrective saccades increased when the line lengths were longer. Hofmeister et al. believed that the corrective saccades correct undershoot and they occur more frequently if the distance between the last word of a line and the first word of the next line is longer. In the second experiment Hofmeister et al. investigated the relation between visuospatial information and return sweep. They presented texts with four different layouts: (1) left and right justified, (2) right unjustfied $\pm$ 3 letters, (3) right unjustified $\pm$ 6 letters and (4) left unjustified. The results showed no difference in return sweep time and accuracy, suggesting that return sweep would be planned from the last fixation on the previous line.

In some studies, return sweeps were excluded (e.g. Bosse, Kandel, Prado, & Valdois, 2014; Henderson & Luke, 2012; Rayner, 1978), whereas some studies specifically looked into return sweeps (e.g., Elterman, Abel, Daroff, Dell'Osso, & Bornstein, 1980; Karnath & Huber, 1992; Trauzettel-Klosinski & Brendler, 1998). In Elterman et al.'s (1980) study, they reported dyslexic children making more or abnormal return sweeps during reading. Karnath and Huber (1992) looked into a patient who suffered from a right basal ganglia infraction with a left-sided hemineglect but with no visual field defect. They reported abnormality in return sweeps. Instead of shifting the eyes to the beginning of the next line, the patient's return sweeps were reduced and the eyes fell into the approximate midpoint of the next line, followed by regressions.

Return sweeps do not only differ in people with reading difficulties. According to Hofmeister et al. (1999), Netchine, Guihou, Greenbaum and Englander (1983) looked into return sweeps in German children and adults. They found that the corrective saccades after return sweeps occurred more for children than for adults. Since the behaviour of return sweeps are found to be different for people with reading difficulties and different ages, we might consider return sweeps as a criterion for reading comprehension. Moreover, should return sweeps be similar across different languages? In this chapter, we are going to investigate return sweeps and corrective saccades in English and Chinese.

7.2 Methodology

The methodology is the same as Chapter 5.

7.3 Hypotheses

We tested the following hypotheses regarding these data:

1. *There will be regressive saccades after return sweeps.*

   In Booth and Weger's (2012) study, they have reported that regressions (i.e. moving backwards) helps readers to reread and comprehend contexts better. Just and Carpenter (1980) have suggested that the eyes may land in the wrong place after return sweeps, which are likely to be longer saccades; thus, the eyes position will be corrected. We looked into saccade data and believed that we would find regressive saccades after return sweeps.

2. *Effect of line-length irregularity gets smaller with successive lines of text.*

   Studies in *Spatial Coding Hypothesis* have suggested that skilled readers are able to code for place when they read (Kennedy, 1986, 1987; Murray and Kennedy, 1988). Murray and Kennedy (1988) have reported that skilled readers had a higher ability to code the spatial location of a word in a sentence than poor readers. We predicted that after each line, there would be more forward eye movements because it gets easier for the readers to locate the beginning of the next line.

7.4 Results

We present the data for the English and Chinese corpora, and for their various subsets, and discuss them with respect to the hypotheses listed above.

The English corpus yielded 110,781 (50.2%) synchronized pairs of saccades out of a total of 441,037, such that the two eyes began and ended the saccades at precisely the same time. The Chinese corpus yielded 117,469 (52.3%) out of 448,949.

1. *There will be regressive saccades after return sweeps.*

   Figure 7.1 shows the English data which demonstrates that the two eyes seem to be moving both forwards and backwards after return sweeps. During normal reading, the two eyes are mostly moving forwards. Table 7.1 details the saccadic movements of normal reading and saccades after return sweeps. Among all data, there are approximately 8.4% of return sweep data. The subgroup of two eyes moving backwards takes up 32.1% on normal reading; whereas about 38.3% of return sweeps are moving backwards. Moreover, the proportion of times the two eyes move in different directions is less than 1% during normal reading and after return sweeps.

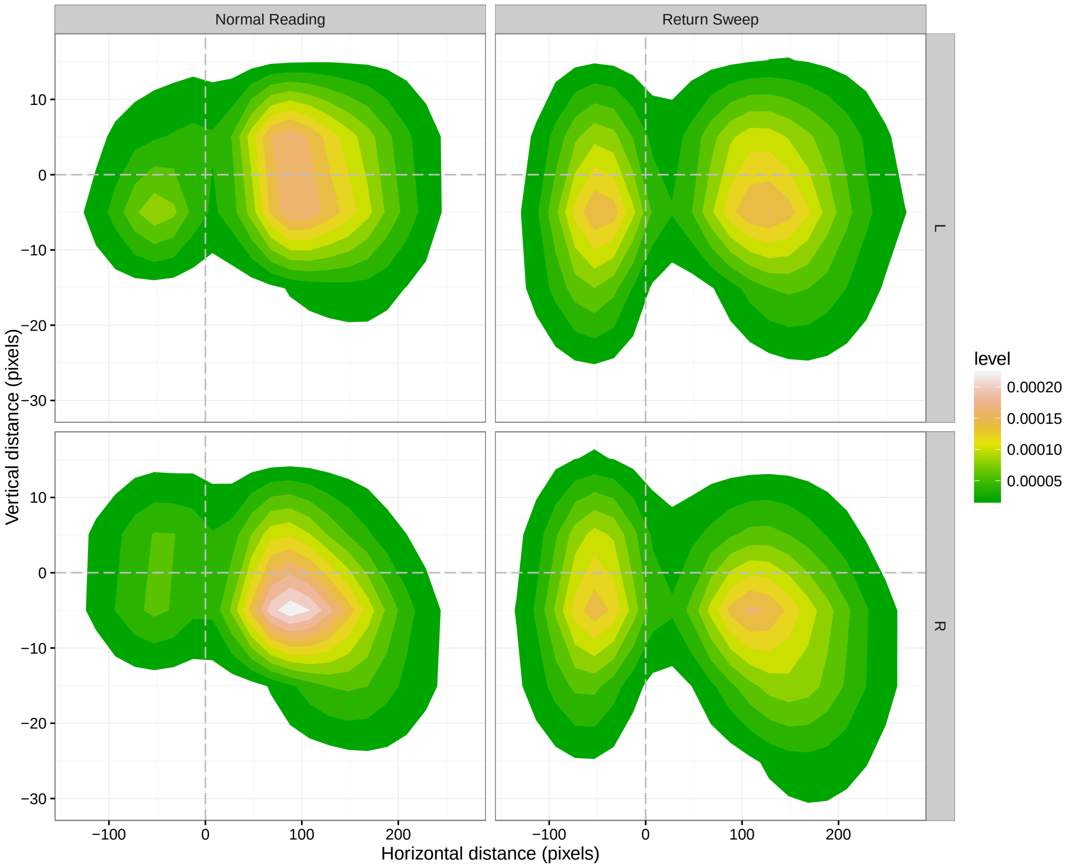

Figure 7.1: Distance in pixels that the two eyes after return sweeps in synchronized English data (110,781 recorded paired saccades).

		Eye Movement Type	
	Eye	Normal Reading	After Return Sweep
Move Backwards	LE	32175 (15.9%)	3545 (19.1%)
	RE	32927 (16.2%)	3558 (19.2%)
Move Forwards	LE	69315 (34.1%)	5728 (30.9%)
	RE	68560 (33.8%)	5718 (30.8%)
Total		202977 (100.0%)	18549 (100.0%)

Table 7.1: Horizontal Saccadic Eye Movements between Two Eyes of Return Sweeps and Normal Reading in English Data (data which shows no saccadic movements is excluded).

Figure 7.2 shows the data for Chinese saccades. The Chinese data shows similar tendency to the English data in normal reading. In return sweeps, however, the data in Chinese tends to move more forwards than in English. Table 7.2 shows that, the proportions of moving forwards and backwards are similar between normal reading (70.7%) and return sweep (71.0%). The proportion is also similar to that in English normal reading (67.9%). The proportion of saccades moving forwards in English return sweep, on the other hand, is the lowest (61.7%).

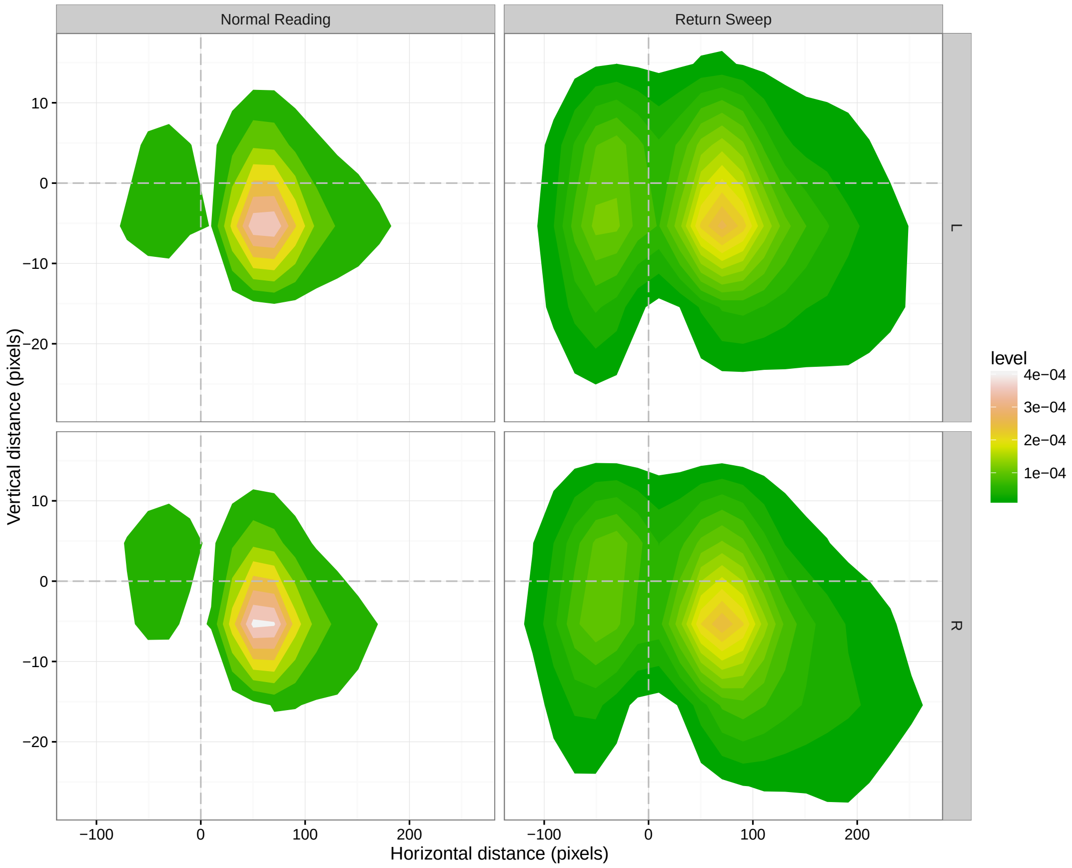

Figure 7.2: Distance in pixels that the two eyes after return sweeps in synchronized Chinese data (117,469 recorded paired saccades).

		Eye Movement Type	
	Eye	Normal Reading	Return Sweep
Move Backwards	LE	31300 (14.4%)	2532 (14.5%)
	RE	32349 (14.9%)	2546 (14.5%)
Moves	LE	77399 (35.6%)	6222 (35.5%)
	RE	76352 (35.1%)	6208 (35.5%)
Total		217400 (100.0%)	17508 (100.0%)

Table 7.2: Horizontal Saccadic Eye Movements between Two Eyes of Return Sweeps and Normal Reading in Chinese Data (data which shows no saccadic movements is excluded).

Compare Figure 7.1 with Figure 7.2, there is a greater deviation in the English saccades than in the Chinese ones. In other words, Chinese saccades are more concentrated and smaller than English saccades, suggesting that the informational density of Chinese is greater.

Table 7.3 and Table 7.4 show the proportion for vertical movements. For saccades during normal reading, there is a greater vertical variance with respect to the left eye in English (Downwards: 28.4%; Upwards: 21.6%) compared with Chinese (Downwards: 33.3%; Upwards: 16.7%), which may refer to the greater variability in English letters (such as ″b″ and ″p″) compared with the more vertically regular Chinese orthography. The right eye, which moves more downwards, follows the left eye, basically observes the known territory. The vertical after return sweeps is quite similar in English and Chinese. We speculate that the moving downwards is the recommencement of to the ″sawtooth″ pattern after return sweeps.

		Eye Movement Type	
	Eye	Normal Reading	Return Sweep
Move Downwards	LE	57397 (28.4%)	5927 (32.1%)
	RE	65510 (32.4%)	6556 (35.5%)
Move Upwards	LE	43559 (21.6%)	3308 (17.9%)
	RE	35503 (17.6%)	2684 (14.5%)
Total		201967 (100.0%)	18475 (100.0%)

Table 7.3: Vertical Saccadic Eye Movements between Two Eyes of Return Sweeps and Normal Reading in English Data (data which shows no saccadic movements is excluded).

We ran linear-mixed effects models using a binomial scheme (Horizontal Saccade Direction [Forward or Backward]) with three random predictors,

		Eye Movement Type	
	Eye	Normal Reading	Return Sweep
Move Downwards	LE	72016 (33.3%)	5667 (32.5%)
	RE	72619 (33.6%)	5922 (33.9%)
Move Upwards	LE	36015 (16.7%)	3051 (17.5%)
	RE	35415 (16.4%)	2803 (16.1%)
Total		216065 (100.0%)	17443 (100.0%)

Table 7.4: Vertical Saccadic Eye Movements between Two Eyes of Return Sweeps and Normal Reading in Chinese Data (data which shows no saccadic movements is excluded).

a separate intercept fitted for participants, a separate intercept fitted for story, and a separate intercept fitted for screen (i.e. page of the text) using the lmer programme in the lme4 (Bates, et al., 2013) package for R (R Core Team, 2012). In our linear mixed effects models, we added a new variable when creating a new model and compared models with and without the new variable. The variable was retained in the new model if the comparison between the two models was significant in a chi-squared test.

We use the function [inv.logit] in R to convert an estimate to a probability (Table 7.5). The predicted probability of moving forwards for saccades after return sweep in Chinese (intercept) (66.1%) was significantly lower than the predicted probability of moving forwards for saccades during normal reading in Chinese (70.3%) (After Return Sweep effects: $z = 7.37$). The predicted probability of saccades moving forwards after return sweep in Chinese (66.1%) was significantly higher than in English (55.8%) (Language effects: $z = -12.5$). There was no significance between the two eyes (LE/RE) across all related parameters. Both eyes are predominantly moving forwards. Within five text lines, the predicted proportion of moving forwards was getting higher. The significant difference of line effects between English and Chinese was marked in the last line (Line 5), where the predicted proportion was still getting higher in English but not in Chinese (Line effects : $z = 4.52$).

2. *Effect of line-length irregularity improves in Chinese.*

   In Table 7.5, it has been shown that the predicted probability of forward movements after return sweep was significantly higher in Chinese (66.1%) than in English (55.8%). We specifically considered Line as one of the variables. Because there was no return sweep in Line 1, we only considered Line 2 to Line 5. In both Chinese and English, the predicted probability tended to slightly increase line by line. In Chinese, the predicted probability of Line 4 (67.0%) was significantly higher than Line 2 (66.1%). In English, the predicted probability of Line 5 (59.4%) is significantly higher than Line 2 (55.8%). In our data, both Chinese and English are five-line texts; however, Table 7.6 has shown that in Chinese, there were far fewer data (6.4%) than other lines. The fifth line in the Chinese stimuli would typically be short, meaning accuracy would increase for the fifth line.

7.5 Discussion

Despite the fact that there are more regressions after return sweeps in English, the proportion of forward movements still takes up more than half in English, suggesting that more than half of the time, readers were able to comprehend and the eyes kept moving forwards. This result confirms Rayner et al.'s (2016) study which has reported that regressions are more important than return sweeps with respect to reading comprehension.

Murray and Kennedy (1988) looked into the eye movements between good readers and poor readers. They found that good readers would make large regressive saccades (more than 20 character space), whereas poor readers made more frequent and shorter backward saccades. They suggested that readers with skilled reading performances had higher ability to code the spatial location of a word in a sentence than poor readers. Here, we found that in both English and Chinese, readers' backward saccades decreased after successive lines.

Sun et al. (1985) reported that the reading patterns of English and Chinese were similar, especially when the eye is not located at the first character of the line after return sweeps. Just and Carpenter (1980) have suggested that the eyes are not properly located after long saccades (ie. return sweeps); therefore, the eyes will make corrective saccades. In our data, we have shown that the eyes tends to move backwards in English more than in Chinese. The English stimuli that were used in our corpus show that the length for each line was different. On the contrary, the length for each line in Chinese was less different (see Appendix G). Therefore, though the first character of each line was at the same place for the two languages (English and Chinese), it was harder for English subjects to locate the correct place after a return sweep because the length of return sweeps would be different.

In conclusion, our study has shown that:

1. *English readers makes more regressions after return sweeps than Chinese readers.*

However, the forward movements still takes up more than half of the proportion in both English and Chinese. Qualitatively, the movement between Chinese and English is similar. There was quantitative difference because of the predictivity of Chinese orthography is greater in the beginning. In English, a line ends with a word and the line lengths could be different in one text. In Chinese, it is very like that, for example, a two-character word can be split into two lines (with the first character being the last character in one line and the second character being the first character in the next following line). The total number of characters and punctuation will be the same in each line. Therefore, the line length is more regular in Chinese than in English.

Qualitatively, tendency of downward movement was the same in both the regressive and the forward movements. Regressive saccades after return sweeps moving downwards is the same as moving forwards. The implication is that, as mentioned in Chapter 6, the progress of each eye across the line of text is a sawtooth, such that the line of sight from the eye tends to fall with respect to the text during the saccade and then tends to climb during the fixation. The downward movements in the regressive and forward movements after return sweeps suggest that the words fall to ventral pathway, which is associated with visual recognition. The regressive saccades after return sweeps are not just for relocating, but also for visual recognition.

Fixed effects:

	Model Estimate	Std. Error	*z* value	*Predicted 1
(Intercept)	0.67	0.19	3.46	66.1%
Normal Reading	0.19	0.03	7.37 ***	70.3%
English	-0.44	0.04	-12.0 5 ***	55.8%
RE	-0.02	0.03	-0.44 *ns.*	65.8%
Line 3	0.02	0.01	1.4 *ns.*	66.6%
Line 4	0.04	0.02	2.48 *	67.0%
Line 5	0.01	0.02	0.37 *ns.*	66.3%
Normal Reading:English	0.31	0.04	8.508 ***	67.5%
Normal Reading:RE	-0.04	0.04	-0.95 *ns.*	69.3%
English:RE	0.01	0.05	0.10 *ns.*	55.5%
English:Line 3	0.01	0.02	0.14 *ns.*	56.3%
English:Line 4	0.02	0.02	0.69 *ns.*	57.2%
English:Line 5	0.13	0.03	4.523 ***	59.4%
Normal Reading:English:RE	0.01	0.05	0.11 *ns.*	66.5%

*Predicted 1: Predicted Probability

Random effects:

	Number	Variance	Std.Dev.
ID	50	0.06	0.23
Article	23	0.05	0.23
Screen Number	10	0.35	0.59

Table 7.5: LME analysis of Probability of moving forwards after return sweeps.

Language Line	Chinese	%	English	%
1	62603	29.6%	50996	25.9%
2	55895	26.4%	45420	23.1%
3	49388	23.3%	42814	21.8%
4	30069	14.2%	34100	17.3%
5	13618	6.4%	23364	11.9%
Total	211573	100.0%	196694	100.0%

Table 7.6: Saccadic data in each line.

Chapter 8

Conclusion

In Chapter 1, Chinese orthography has been introduced. The linguistic information that a Chinese character can give is more than simply sounds; moreover, it can contain semantic information. Being a logographic orthography, is the visual process of reading and perceiving Chinese the same as alphabetical orthography such as English? We have investigated the Chinese orthography by its characters, words, and reading behaviours.

In Chapter 2, we firstly introduced the effect of orthographic satiation (Cheng & Wu, 1994), which refers to the feeling of uncertainty about the composition of a Chinese character after prolonged viewing of the character. This effect has been specifically addressed in logographic languages such as Chinese and Japanese (e.g., Cheng & Wu, 1994; Ninose & Gyoba, 1996). However, the similar phenomenon of feeling a word decomposing or losing its gestalt was first reported by Severance and Washburn (1907).

Due to the distinctiveness between alphabetic and logographic languages, we believe that the effects of prolonged inspection of a Chinese character may be expected to be different from those reported in English. In Lee's study (2007), which extended Cheng and We's study (1996), the results showed that orthographic satiation occurred faster in females than males. Lee found a sex difference and suggested that female participants stored the whole character in assembled form, making it more liable to satiation, compared with the male strategy of assembling the representation while processing it. Therefore, in Chapter 3, we replicated Lee's study, and found that:

1. **a radical that can stand alone as a single character makes characters in which it occurs resistant to satiation;**

   A significant effect emerged with respect to radical status: characters that contained only one radical that could legally stand alone, or no such radical, were more likely to satiate than characters that contained two radicals that could legally stand alone. The result was in line with our discussion, regarding the varying extent to which (English) words are processed with respect to their external constraints. Our data extend this discussion to Chinese orthography and to the orthographic satiation effect.

2. **no reliable effect of the sex of the participant on Chinese orthographic satiation.**

   Satiation did not tend to occur significantly more in females than in males. The results were numerically in the opposite direction to those in Lee's study. Similarly, there was no significant effect of radical order, the most salient difference within our very closely matched stimuli.

Following orthographic satiation, we discussed another visual effect, foveal splitting in Chapter 2. We reviewed studies of foveal splitting in reading Chinese (Hsiao and Liu, 2010; Hsiao & Shillcock, 2005; Hsiao, Shillcock, & Lavidor, 2006; Hsiao, Shillcock and Lee, 2007), and then reviewed studies that reported finding contralateral preference (e.g., Hemond & Kanwisher, 2007; Niemeier et al., 2005; Toosy et al., 2001). Nevertheless, what will the results be when words

$$\begin{bmatrix} LE & \rightarrow & RH \\ RE & \rightarrow & LH \end{bmatrix} > \begin{bmatrix} RE & \rightarrow & RH \\ LE & \rightarrow & LH \end{bmatrix}$$

Contralateral visual pathway　　　Ipsilateral visual pathway

Figure 8.1: Eye/hemisphere contralateral preference.

are presented to the eyes? In Obregón and Shillcock's (2012) study, they conducted a haploscope experiment to investigate eye/hemisphere visual pathway preferences (Figure 8.1) using four-letter English words, and reported a tendency for subjects to be more accurate when the stimuli were presented contralaterally.

In Chapter 4, we extended Obregón and Shillcock's (2012) study by using Chinese characters and words to see if the contralateral preference will still be found regardless of the different types of orthographies. Our results showed that:

1. **the contralateral visual pathway was preferred in perceiving right-left structured Chinese characters and two-character words.**

   The result was consistent with Obregón and Shillcock's (2012) study which has reported the eye/hemisphere contralateral preference. We have proved that even when perceiving Chinese orthography which is more complex visually than English, the contralateral visual pathway is still preferred.

2. **Males did better than females recognizing characters but not words**

   In a single-character presentation (Experiment 2), we found that males did significantly better than females. In Tan et al.'s study(2001), they found that RH regions activated more in reading Chinese than in reading English, suggesting that the processing of Chinese characters required an analysis of spatial information of strokes. Moreover, Huestegge et al.

(2012) have reported that males were better in visuospatial tasks involving memory, while females performed better in verbal tasks. We believe that males have been found to perform better because perceiving Chinese characters required the analysis of spatial information.

However, why was there no significance in two-character word presentation (Experiment 4)? Though males have been proved to perform better in visuospatial tasks (e.g., Huestegge, et al., 2012), females have been found to perform better than males in reading (e.g., Mikk & Lynn, 2009). Tan and Perfetti (1999) have proposed that two-character words contain two separate characters and the identification has been found to involve higher level processing by sustaining a constituent analysis and assembly process. That is, recognition of Chinese words involves a higher-level process.

3. **RH obtained higher mean scores in character recognition, on the contrary, LH obtained higher mean scores in word recognition.**

   As we mentioned in Chapter 4, Hsiao and Cottrell (2009) found that native Chinese readers exhibited a left-side bias in character recognition, but not in novice Chinese learners. Their finding suggests that the holistic processing may be reduced for native Chinese readers. Native Chinese readers learn to facilitate character recognition by isolating the component of Chinese characters when the component appears in other Chinese characters repetitively.

   The processing of two-character words which contain more information than single characters is more complex. Tan and Perfetti (1999) reported that the processing of two-character Chinese words involves a constituent analysis and assembly process. The LH is specialized as a temporal and sequential analyzer. Therefore, processing two-character words should be more lateralised in LH, causing the lower mean score in RH.

4. **Semantic components that are projected to the LH will be recognised better.**

   When looking into SP-PS characters, we have found that the preference of eye/hemisphere contralateral visual pathway is cancelled out. We only recruited female participants, and the result which showed PS getting significantly better scores than SP confirmed Hsiao and Shillcock's (2005) finding which showed that females tended to respond to PS slightly faster than SP. Ding et al. (2016) have explored brain atrophy of native Chinese speakers with semantic dementia. They found that the gray matter of left fusiform gyrus and left parahippocampal gyrus have a significant correlation with the semantic scores of patients with semantic dementia, suggesting that some regions of the LH one important when processing semantics. This finding is aligned with our result that people got higher scores when semantic radicals were projected to the LH.

5. **the larger a neighbourhood size was, the better participants were able to recognise part of the words.**

After exploring the visual recognition of Chinese characters and words, we looked into reading behaviours in both English and Chinese. We discussed small eye movements that occurred within fixations. Tremor, the smallest wave-like movement, is one of the small eye movements and its frequency is around 90 Hz (Martinez-Conde, Macknik, & Hubel, 2004). In Chapter 5, we explored the small eye movements within fixations and compared the differences and similarities in regards of physical eye movements between English and Chinese. We found that:

1. **the majority of the fixations were crossed.**

Some studies (e.g., Jainta, Hoormann, Kloke, & Jaschinski, 2010; Nuthmann & Kliegl, 2009) have reported that the two eyes are predominantly crossed in most fixation data. It has been reported that when using Eyelink technology, more crossed FDs are elicited, while more uncrossed FDs are elicited using Dual Purkinje technology. Shillcock et al. (2010) have concluded that this difference is due to the viewing conditions. The proportions of crossed and uncrossed FDs we reported reflect the general fixation behaviours observed with the viewing conditions allowed by Eyelink technology, which involves reading in a normal room lighting and on dark-on-light text (cf. Kirkby et al., 2008; Shillcock et al., 2010).

2. **there was more divergence within fixations in the reading of Chinese than in the reading of English.**

   Studies have shown that when images of objects appear to be presented farther away, the brain tends to process the images more accurately (Arnold & Schindel, 2010; Kersten & Murray, 2010). Based on the studies above, we predicted that readers Chinese orthography produced more divergence (a 'zoom in' effect) within fixations because Chinese is more visually complex than English. We confirmed that the 'zoom in' effect occurred more in Chinese, and we also found that Chinese readers changed FDs from crossed to uncrossed more than the readers of English orthography.

In conclusion, we confirmed that using Eyelink technology, crossed disparities are predominant. Moreover, we found and confirmed that the 'zoom in' effect occurs during reading. This effect, which facilitates the allocation of cortical resources to the visual field, helps readers to read easier.

In Chapter 6, we still looked into eye movements within fixations, and we specifically investigated the role of vertical disparities between Chinese and English. We found that:

1. **Vertical movements within a fixation tend to be smaller than horizontal ones.**

   Our data show a more even vertical distribution compared with the horizontal distribution, especially in English. We believed that, to some extent, these data reflect inherent differences between single-line and multi-line reading, and to some extent they reflect the fact that eye-tracking is typically more reliable in the horizontal dimension, compared with the vertical.

2. **Vertical movements within a fixation tend to be upwards.**

   In Chapter 4, we looked into two horizontal visual pathways, contralateral and ipsilateral pathways. We have found that the contralateral visual pathway is preferred when presenting Chinese characters and two-character words. When speaking of cortical visual processing, two distinct pathways, the dorsal and the ventral pathways, usually occur to people's mind. However, the question of how the visual pathways play a role in reading seems to remain controversial. The dorsal-ventral distinction has a long history in cognitive neuropsychology (e.g., Hickok, & Poeppel, 2004; Singh-Curry, & Husain, 2009) The ventral route is associated with visual template matching and meaning; whereas the dorsal route is associated with spatial processing and executive action.

   The upper visual field projects to the ventral pathway, and the lower visual field to the dorsal pathway (cf. Previc, 1990). We speculate here that the earlier part of the fixation is associated with visual recognition and for the later part of the fixation to be associated with executive action.

The tendency to move upwards also fits in with the idea that, not only in single word recognition (Blais et al., 2009; Chi, Yan, Meng, Zang, & Liversedge, 2015; Perea, Comesaña, & Soares, 2012; Perea, Comesaña, Soares, & Moret-Tatay, 2012) but also in real-world reading, the upper part of words/characters are relatively more informative.

In conclusion, we explored eye movements within fixations with regards to the vertical dimension. We found that vertical disparity is smaller and more symmetric than horizontal disparity. Moreover, the eyes are found to move more upwards within fixations, this finding has suggested that the dorsal and ventral pathways are differentially employed during a fixation, and also reflected the fact that the upper part of words/characters are relatively more informative during reading.

Lastly, we explored a physical effect, return sweep, that occurs during reading. We looked into saccades during normal reading and after return sweeps and compared English with Chinese. We found that:

1. **English readers makes more regression after return sweeps than Chinese readers.**

   Just and Carpenter (1980) have suggested that the eyes are not properly located after long saccades (ie. return sweeps), so the eyes will make corrective saccades after long saccades. Sun et al. (1985) have reported that when the eye was not located at the first character of the line after return sweeps, the reading patterns of English and Chinese were qualitatively similar. In our data, the stimuli that were used in our corpus were such that the length for each line could be different. Comparing English text with Chinese, the line lengths varied more in the English (see Appendix G). The data has shown that the eyes tends to move backwards in English more than in Chinese, after a return sweep. Therefore, though the first character of each line was at the same place for two languages (English and Chinese), it was harder for English subjects to locate the correct place after return sweeps because the lengths for return sweeps have been more varied.

2. **Effect of line-length irregularity improves.**

   According to the Spatial Coding Hypothesis, skilled readers are able to code and reinspect the places in text that are informative (e.g., Kennedy, 1986, 1987). Murray and Kennedy (1988) looked into eye movements for people with different reading levels. They found that high-level readers made large regressive saccades (more than 20 character space), whereas poor readers made more frequent and shorter backward saccades. They suggested that readers with skilled reading performances had a higher ability to code the spatial location of a word in a sentence than poor readers. Here, we found that in both English and Chinese, readers' regressive saccades decreased after successive lines. In other words, readers are able to locate the first character more accurately line on line.

In conclusion, this thesis investigated closely the visual perception in Chinese orthography, with respect to characters, words, and real-word reading. We looked into existing effects that have been found in English or Chinese (e.g., loss of perceptual coherence and contralateral preferences), and tried to replicate the effects in Chinese. Moreover, we compared the differences and similarities between languages (English and Chinese). Despite the fact that the orthographies of English and Chinese are very different, we still found similar effects (e.g., the contralateral preference) between them. This thesis thus has contributed to a better understanding of the differences and similarities between reading English and Chinese orthographies.

Appendices

Appendix A

Experimental materials for Experiment 1: Fading Effecat in SP and PS characters

Semantic-Phonetic characters

SP1: 狼　SP2: 詰　SP3: 祥　SP4: 惕

SP5: 據　SP6: 涕　SP7: 凋　SP8: 裕

SP9: 押　SP10: 訟　SP11: 堪　SP12: 檢

SP13: 擠　SP14: 嘔　SP15: 餓　SP16: 幅

SP17: 扮　SP18: 徐　SP19: 課　SP20: 滴

Phonetic-Semantic characters

PS1: 郎　PS2: 頡　PS3: 翔　PS4: 剔

PS5: 劇　PS6: 剃　PS7: 雕　PS8: 欲

PS9: 鴨　PS10: 頌　PS11: 勘　PS12: 劍

PS13: 劑　PS14: 毆　PS15: 鵝　PS16: 副

PS17: 頒　PS18: 敘　PS19: 顆　PS20: 敵

Appendix B

Questionnaire for self-report in Experiment 1: Fading Effect in SP and PS characters

Part I. Participant's background

1. Name initials:
2. Gender: male/female
3. Age:
4. Handedness: right/left handed
5. Nationality:
6. Native language: Mandarin Chinese/ Taiwanese/ Hakka/ Formosan languages/ other:
7. Programme of study:
8. Time of living in Taiwan:

9. When did you begin to learn reading Chinese characters and how long is your experience in reading Chinese characters?

10. How long have you stayed in Scotland?

Part II. Participant's background

1. Have you experienced Chinese satiation before? (Yes $\rightarrow$ 2; No$\rightarrow$ 3)

2. How often does the effect occur? Under what kind of circumstances it occurs more often?

3. Please describe how characters appear to you after you press the buttons during the experiment. (ex. The change of shape)

4. After orthographic satiation occurs, does such feeling remains while staring at the characters or does the character become normal to you again and then strange again?

5. Please describe anything you felt special in reading Chinese characters during the experiment.

Appendix C

Experimental materials for Experiment 2: Contralateral and Ipsilateral Visual Pathways in Chinese Character Perception

Char001	能	Char002	時	Char003	說	Char004	他
Char005	那	Char006	提	Char007	請	Char008	所
Char009	得	Char010	對	Char011	都	Char012	機
Char013	站	Char014	知	Char015	很	Char016	何
Char017	地	Char018	於	Char019	嗎	Char020	現
Char021	新	Char022	和	Char023	點	Char024	科
Char025	清	Char026	此	Char027	吧	Char028	行
Char029	經	Char030	城	Char031	動	Char032	比
Char033	像	Char034	外	Char035	該	Char036	性
Char037	程	Char038	龍	Char039	別	Char040	灣
Char041	部	Char042	歡	Char043	代	Char044	影
Char045	叫	Char046	保	Char047	份	Char048	決

Char049	組	Char050	級	Char051	持	Char052	投
Char053	喔	Char054	流	Char055	貓	Char056	門
Char057	般	Char058	觀	Char059	聯	Char060	朋
Char061	吃	Char062	錄	Char063	換	Char064	板
Char065	形	Char066	類	Char067	似	Char068	引
Char069	制	Char070	驗	Char071	怪	Char072	滿
Char073	收	Char074	眼	Char075	課	Char076	願
Char077	夠	Char078	往	Char079	碟	Char080	離
Char081	段	Char082	證	Char083	列	Char084	剛
Char085	殺	Char086	切	Char087	跑	Char088	執
Char089	斯	Char090	例	Char091	油	Char092	救
Char093	終	Char094	印	Char095	斷	Char096	環
Char097	疑	Char098	仍	Char099	佛	Char100	顯
Char101	配	Char102	敗	Char103	楊	Char104	灌
Char105	狂	Char106	戲	Char107	狗	Char108	維
Char109	陸	Char110	忙	Char111	江	Char112	冷
Char113	創	Char114	仁	Char115	劍	Char116	缺
Char117	松	Char118	射	Char119	昨	Char120	彩
Char121	欣	Char122	鐘	Char123	付	Char124	私
Char125	鬥	Char126	帥	Char127	輔	Char128	默
Char129	郎	Char130	傑	Char131	絲	Char132	弱
Char133	獻	Char134	耀	Char135	池	Char136	仰
Char137	舒	Char138	飲	Char139	啪	Char140	欄
Char141	鮮	Char142	污	Char143	彰	Char144	狐
Char145	汪	Char146	砲	Char147	杜	Char148	獸
Char149	玫	Char150	潛	Char151	弦	Char152	泥
Char153	億	Char154	勁	Char155	甜	Char156	幼
Char157	軒	Char158	鑑	Char159	刪	Char160	擋

Char161	姆	Char162	嫌	Char163	扣	Char164	潔
Char165	抄	Char166	穌	Char167	騷	Char168	貌
Char169	融	Char170	儒	Char171	飾	Char172	擠
Char173	弘	Char174	敦	Char175	仲	Char176	駛
Char177	仇	Char178	牧	Char179	殼	Char180	毅
Char181	悦	Char182	賭	Char183	疏	Char184	欽
Char185	鵝	Char186	刑	Char187	纏	Char188	鄧
Char189	併	Char190	汗	Char191	泛	Char192	櫃
Char193	札	Char194	詠	Char195	羯	Char196	嫁
Char197	桶	Char198	獵	Char199	勳	Char200	吋
Char201	硒	Char202	矩	Char203	辣	Char204	肆
Char205	歧	Char206	鈞	Char207	黏	Char208	蹈
Char209	汁	Char210	佬	Char211	郝	Char212	伐
Char213	畔	Char214	頸	Char215	枕	Char216	枚
Char217	齣	Char218	仟	Char219	詰	Char220	錐
Char221	戳	Char222	肺	Char223	阱	Char224	輒
Char225	汐	Char226	儡	Char227	矽	Char228	楷
Char229	鄒	Char230	勘	Char231	殲	Char232	馴
Char233	淌	Char234	曜	Char235	扛	Char236	耽
Char237	鋸	Char238	轅	Char239	絨	Char240	訶
Char241	吭	Char242	梓	Char243	騁	Char244	幟
Char245	妃	Char246	炊	Char247	塚	Char248	炬
Char249	桐	Char250	踹	Char251	鞠	Char252	睏
Char253	郡	Char254	鉅	Char255	艷	Char256	酵
Char257	骯	Char258	煒	Char259	韌	Char260	絞
Char261	嫣	Char262	昀	Char263	酹	Char264	眨
Char265	韶	Char266	絢	Char267	汎	Char268	鸚
Char269	騏	Char270	砰	Char271	眩	Char272	杭

Char273	棘	Char274	跎	Char275	兢	Char276	勛
Char277	圳	Char278	怔	Char279	眛	Char280	訟
Char281	翊	Char282	譎	Char283	昕	Char284	骸
Char285	貍	Char286	敕	Char287	鸝	Char288	隍
Char289	仆	Char290	陞	Char291	燉	Char292	吁
Char293	孜	Char294	潢	Char295	剷	Char296	枋
Char297	鉦	Char298	鮭	Char299	骼	Char300	靦
Char301	餞	Char302	屹	Char303	蛟	Char304	糰
Char305	吒	Char306	狩	Char307	鷚	Char308	餚
Char309	嚏	Char310	邢	Char311	忖	Char312	戕
Char313	鯛	Char314	怦	Char315	刈	Char316	軛
Char317	囍	Char318	俚	Char319	涸	Char320	愾
Char321	斡	Char322	濠	Char323	錠	Char324	鎊
Char325	蛔	Char326	甌	Char327	擤	Char328	釦
Char329	黠	Char330	鱔	Char331	砧	Char332	汕
Char333	輊	Char334	氈	Char335	撻	Char336	杷
Char337	燎	Char338	佃	Char339	軻	Char340	踉
Char341	侄	Char342	顢	Char343	酢	Char344	鰓
Char345	酚	Char346	鳩	Char347	覲	Char348	驃
Char349	舺	Char350	祛	Char351	皰	Char352	賒
Char353	砒	Char354	鯁	Char355	蠑	Char356	阡
Char357	枸	Char358	枇	Char359	媧	Char360	貘
Char361	顴	Char362	鱒	Char363	伉	Char364	赧
Char365	牘	Char366	揠	Char367	踟	Char368	踊
Char369	舐	Char370	鶚	Char371	剉	Char372	訌
Char373	牝	Char374	匏	Char375	沏	Char376	胰
Char377	砵	Char378	汛	Char379	魹	Char380	谿
Char381	圮	Char382	舛	Char383	齜	Char384	歆

Char385	膻	Char386	蜆	Char387	僂	Char388	仨
Char389	玨	Char390	瀡	Char391	駙	Char392	褵
Char393	酎	Char394	鮒	Char395	騶	Char396	潟
Char397	邛	Char398	鈤	Char399	髂	Char400	鶡

Appendix D

Experimental materials for Experiment 3: Contralateral and Ipsilateral Visual Pathways in SP-PS Chinese Character Perception

PS01	郎	PS02	頡	PS03	翔	PS04	瓶	PS05	劍
PS06	劑	PS07	鵝	PS08	剔	PS09	劇	PS10	助
PS11	魁	PS12	副	PS13	雕	PS14	頒	PS15	敘
PS16	欲	PS17	鴨	PS18	敵	PS19	頌	PS20	勘
PS21	旭	PS22	郁	PS23	歇	PS24	刻	PS25	敏
PS26	翅	PS27	刊	PS28	敞	PS29	豁	PS30	剖
PS31	頓	PS32	敦	PS33	匙	PS34	創	PS35	卦
PS36	鵲	PS37	皺	PS38	刮	PS39	胡	PS40	勁
PS41	削	PS42	彩	PS43	劏	PS44	彰	PS45	勃
PS46	剛	PS47	顱	PS48	離	PS49	政	PS50	邱
PS51	顧	PS52	頂	PS53	鴉	PS54	願	PS55	欺
PS56	飄	PS57	觀	PS58	郊	PS59	鄰	PS60	鄧

PS61	放	PS62	領	PS63	叩	PS64	顏	PS65	致
SP01	狼	SP02	詰	SP03	祥	SP04	拼	SP05	檢
SP06	擠	SP07	餓	SP08	惕	SP09	據	SP10	組
SP11	愧	SP12	幅	SP13	凋	SP14	扮	SP15	徐
SP16	裕	SP17	押	SP18	滴	SP19	訟	SP20	堪
SP21	仇	SP22	賄	SP23	竭	SP24	核	SP25	悔
SP26	歧	SP27	軒	SP28	倘	SP29	轄	SP30	賠
SP31	純	SP32	醇	SP33	堤	SP34	槍	SP35	蛙
SP36	醋	SP37	趨	SP38	恬	SP39	枯	SP40	徑
SP41	逍	SP42	採	SP43	鏟	SP44	蟑	SP45	脖
SP46	鋼	SP47	爐	SP48	璃	SP49	証	SP50	蚯
SP51	僱	SP52	訂	SP53	訝	SP54	源	SP55	棋
SP56	漂	SP57	灌	SP58	狡	SP59	憐	SP60	瞪
SP61	防	SP62	玲	SP63	扣	SP64	諺	SP65	姪

Appendix E

Experimental materials for Experiment 4: Contralateral and Ipsilateral Visual Pathways in Two-Character Chinese Words Perception

W001	我們	W002	學生	W003	大家	W004	國家
W005	大學	W006	孩子	W007	不同	W008	中心
W009	進行	W010	其他	W011	發生	W012	歷史
W013	朋友	W014	任何	W015	媽媽	W016	父母
W017	運動	W018	訓練	W019	爸爸	W020	目的
W021	自然	W022	一下	W023	階段	W024	男人
W025	不少	W026	價格	W027	開發	W028	範圍
W029	北京	W030	歐洲	W031	不錯	W032	左右
W033	出來	W034	大衆	W035	策略	W036	大型
W037	吸引	W038	樣子	W039	訊息	W040	主動
W041	女孩	W042	國人	W043	信心	W044	大會
W045	一生	W046	遇到	W047	如何	W048	人人

W049	一日	W050	細胞	W051	立委	W052	退休
W053	單純	W054	病患	W055	五千	W056	八十
W057	開口	W058	此刻	W059	大戰	W060	百姓
W061	新家	W062	轉學	W063	鐲子	W064	旗子
W065	勸阻	W066	寬裕	W067	種田	W068	萬芳
W069	臍帶	W070	鞭打	W071	慘烈	W072	妹妹
W073	鼻孔	W074	轉化	W075	談吐	W076	僵持
W077	彈珠	W078	轉告	W079	聽出	W080	燙到
W081	鄰人	W082	謝玄	W083	賣弄	W084	繩索
W085	擁抱	W086	變性	W087	轉行	W088	離心
W089	腐敗	W090	閻王	W091	賭王	W092	懲戒
W093	厘米	W094	潛逃	W095	膠帶	W096	檜木
W097	難行	W098	轉回	W099	變大	W100	轉帳
W101	轉世	W102	購屋	W103	體長	W104	體色
W105	驢子	W106	關起	W107	鹽巴	W108	轉角
W109	難過	W110	轉口	W111	變心	W112	關子
W113	體用	W114	峇里	W115	侄子	W116	夯土
W117	庄腳	W118	囡仔	W119	憨人	W120	碴子

Appendix F

Experimental materials for Experiment 6: Binocular Rivalry in Chinese characters

Grammatical

G01-1	狼	G01-2	祥	G02-1	徐	G02-2	核
G03-1	悔	G03-2	徑	G04-1	竭	G04-2	槍
G05-1	滴	G05-2	傕	G06-1	詰	G06-2	賄
G07-1	蛙	G07-2	証	G08-1	惕	G08-2	採
G09-1	訟	G09-2	蚯	G10-1	組	G10-2	訝
G11-1	堤	G11-2	脖	G12-1	愧	G12-2	源
G13-1	幅	G13-2	堪	G14-1	裕	G14-2	棋

Ungrammatical

U01-1	虫止	U01-2	食九
U02-1	木齊	U02-2	目彦
U03-1	止丁	U03-2	犭卩
U04-1	女登	U04-2	酉岡
U05-1	貝我	U05-2	目享

U06-1	車圭	U06-2	酉尹
U07-1	犭害	U07-2	氵 芻
U08-1	礻每	U08-2	阝孛
U09-1	王巠	U09-2	立至
U10-1	扌良	U10-2	阝尚
U11-1	食正	U11-2	土苗
U12-1	糸辰	U12-2	彳
U13-1	月皆	U13-2	考
U14-1	亻房	U14-2	虫川

Appendix G

Reading materials in Edinburgh Five-Language Reading Corpus

Jan Hanson was an early walker and talker. At six he was asking how light works and deducing that sound must also work in waves. He liked to discuss chaos theory. Two years later – struggling to fit into school – he was writing a poem about suicide.

His school life remained a rollercoaster of unsympathetic heads, oddball friends, boring lessons and feelings of being an outsider. He moved school often and never settled. Only now, aged 19 and halfway through a degree in theoretical physics, has he started to find his feet.

His brother is faring even worse. He was accelerated three years ahead of his age group at his Berkshire prep school, but ran into serious social problems, was excluded, attended a pupil-referral unit, and is now being taught at home.

Both boys belong to the top half per cent of the ability range – the pupils we used to call child prodigies and geniuses. But their mother would not consider this giftedness a blessing. That is because super-bright children are not catered for in schools.

Many find it impossible to survive there, and the parents who then have to struggle to tutor them at home grow increasingly angry that so little is being done for them. Today, it is broadly accepted that gifted and talented children need help to stretch their brains and extend their interests.

But, faced with a child who is not just clever, but who can do university-level work at nine, schools throw up their hands. Often they find it hard to accept that a child can really be as bright as they are, and decide that the parents must be pushing him or her.

A further complication for super-bright children is that their giftedness can often be coupled with conditions such as dyslexia or Asperger's syndrome, which leave schools even more flummoxed.

Teachers are often challenged and unsettled by such children, parents get angry that their children's needs are not acknowledged, and situations quickly grow emotional and entrenched. But schools must learn to listen more to the children, and to their parents.

A few institutions are planning to axe age-groups and let students go at their own pace, but most still believe that children should fit schools, not schools children. This leaves parents forced into being home-educators against their will. And it leaves them furious.

星期二的下午，台北市陽光正烈。一棟大樓裡，冷氣剛好，音樂流瀉，一群穿著舞衣的學生們，正跟著美麗女老師清脆的聲音，舉手扭腰、轉身抬腿，一靜一動之間，如此優雅。她們在跳芭蕾舞！

三點半，下課了，學生們魚貫而出。換衣服的、沖澡的、喝水的、聊天的，空氣中飄散著喧嘩的人聲和運動後特有的氣味，每個人的臉上都紅通通的。這些人有的是牙醫、有的是空姐，還有出版社編輯、媒體記者、專欄作家、退休小學老師和教鋼琴的音樂老師。

曾幾何時，學習芭蕾舞悄悄在台北市流行了起來。和芭蕾一樣風起雲湧的，還有中東肚皮舞和薩爾薩舞，每天都有不少電話專門詢問：何時要開薩爾薩舞班？每次一開課，總是班班爆滿。

對許多都會女性上班族來說，不需要花太多時間，一星期跳個兩次芭蕾舞，基本運動量就足夠了。再加上芭蕾舞可以修飾體型，不消幾個月，手腳明顯地修長起來，舉手投足間，自然流露出一種跳芭蕾舞的氣質，就像是舞蹈美容一般，難怪在學員口耳相傳下，迅速流行。

這一波新興舞蹈教室，所有的老師都是專業舞者，來自不同舞團，各有各的專長。他們會注意基本動作，更會留心運動傷害。有些舞蹈教室更是多才多藝，從現代舞、爵士舞到太極導引都有。特別的是還有編舞，對於已經有舞蹈底子的學生來說，透過舞蹈來創作，又是一種截然不同的體驗。

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