

Inter-ocular Facilitation and Suppression in the Reading of Chinese Characters

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1. Introduction and Purpose

An overwhelming amount of research has generalized rules to the psycholinguistic mechanisms underlying visual word recognition. Most theories are based on studies of Indo-European languages in general, English in particular. Naturally, due to the universal principal of language, some researchers believe that the application of theories of language processing is universal despite that they were built on observations from specific languages. Conversely, other researchers think that language-specific variations warrant different psycholinguistic mechanisms for typologically different languages. To resolve the tension between the two perspectives, cross-linguistic methods in language processing thus become the focus of the field. Comparisons across languages allow researchers to investigate the universalities and the specificities of language processing. Therefore, in recent years, researchers have shown an increased interest in the study of non-alphabetic languages because of its different formats in the way that various orthographies represent spoken languages. Much debate has focused on whether orthographic-specific processing is related to the reading of different orthographies.

This dissertation provides a test ground for theories in isolated word recognition and the implications of binocularity by using a non-alphabetic, logographic, language: Chinese.

Visual Field Integration and Binocular Rivalry

Humans, as with most mammals, have two eyes that enable us to navigate ourselves adaptively in the environments. The binocular vision allows us to perceive the depth of objects, as well as to have a relatively wide visual field, therefore, is extremely crucial to our survival. In order to achieve complete binocularity, we have to combine the information projected onto the two eyes, through the optic nerve to the brain. However, the underlying mechanism of the integration of information from the left and right visual fields in the human visual pathway is still uncovered.

Given that a large body of research has suggested that language is predominantly processed in the left hemisphere of the brain, investigation in language processing would provide a good test case for the issue of left-right field integration in visual perception. In the past few decades, there has been a controversy as to the relationship between the two visual fields (left and right) and the two brain hemispheres (left and right), particularly in the domain of reading (where the objects are not mirror imaged). The '*split fovea*' hypothesis (e.g., Shillcock & Robert, 2010; Hsiao,

Shillcock, & Lee, 2007) claims that the human fovea is vertically split into two areas functionally and anatomically, and the left part of the word is projected onto the right half fovea of both left and right eyes, and then both foveal images are integrated and transferred onto the right hemisphere (for the right part, vice versa). Consequently, according to this account, different information would be initially sent to, and processed in, the two hemispheres. In contrast, the *bilateral representation* hypothesis, a more traditional account, argues that information on the fovea of each eye is transferred onto both hemispheres, which suggests that the two hemispheres would process identical information (e.g., Stone, Leicester, & Sherman, 1973; Trauzettel-Klosinski & Reinhard, 1998).

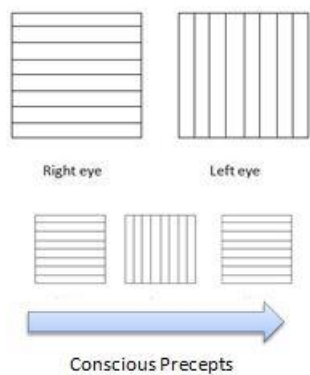


Figure 1: an example of binocular rivalry

Additionally, apart from the implication of inter-hemispheric pathways, there is another critical implication of binocularity that has attracted much curiosity as well as debate, a phenomenon called *binocular rivalry*. In nature, binocular vision functions the best when two eyes are presented to similar objects. Interestingly, when two different visual stimuli are presented to two eyes, the perception is an alternation of the two eyes' view. This curious result is binocular rivalry. For instance, if a set of horizontal lines is presented to the left eye when a set of vertical lines is presented to the same region of retina of the right eye, instead of seeing two different images, our brain fuses

two images into one single perception. Sometimes the horizontal lines are seen without any trace of vertical lines, and sometimes vice versa (see Figure 1). The switching process is the critical aspect to why researchers are interested in binocular rivalry as it reveals the variations of consciousness and is also a key to understanding the neural mechanisms of conscious experience.

It has been argued binocular rivalry might employ the same underlying neural mechanism(s) with visual attention (Lomas, Piggins, & Phillips, 1998), e.g., both involve the selection of information. The traditional account suggested that binocular rivalry occurs early in the visual pathways (e.g., Blake, 1989). However, recent evidence shows that binocular rivalry occurs between neural representations at a high level in the visual pathway (Logothetis, Leopold, & Sheinberg, 1996). In contrast to the monocular channel competition model (i.e., neurons

responsive to input from only one eye) that the traditional account supported, recent findings suggest an inter-hemispheric switch model in which one cerebral hemisphere's high level visual processing regions adopt one of the rivaling perceptions, while the other hemisphere adopts the other perception. Competition for awareness during rivalry is therefore occurring between each hemisphere's higher visual regions (a competition between visual representations).

This dissertation thus will address the question of the integration of visual information in reading Chinese characters in which how the structural and lexical properties of Chinese characters influence the binocularity and rivalry processing (e.g., the selection of information during binocular rivalry). Chinese orthography employs stroke-patterns or characters rather than alphabetic letters. Chinese characters are dense and logographic. Thus, most single Chinese characters contain both semantic and phonological information in different components (radicals), often predictably on the left or right of the character. Thus, this configuration maps onto meaningful morphemes as well as phonemes in the spoken language. This structure provides opportunities to investigate structural and lexical aspects of visual language processing which might potentially involve cognitive processing that is different from alphabetic orthographies.

In the experiment, binocular rivalry was induced by using a dichoptic stimulation (a haploscope) to investigate the process by which a Chinese character projected to one eye is able to break through the influence of a pattern mask presented to the other eye. Potentially, there is scope for considerable complexity of interaction between (i) semantic and perceptual content of the visual hemifield, (ii) anatomical details of the visual pathway from cornea to cortex, (iii) hemispheric processing preferences.

Understanding more about binocular interactions will inform our evolutionary perspective on hemispheric differences in cognition forming a platform for intersubjectivity, i.e., my left hemisphere using visual information to find out about what my right hemisphere is doing gives it the tools to find out what your right hemisphere is doing (Shillcock & Bailes, in prep.). The goal of this dissertation is to compare the influence of different types of Chinese characters on interocular suppression. Potentially, the collected data in this dissertation does not only concern processing relevant to character and word recognition, but also evolutionarily much older processing, such as spatial cognition (due to the fact that Chinese characters have complex internal structures within themselves) and object recognition (due to the fact that some components are highly pictographic). It follows that reading could be situated within much wider perceptual and cognitive processing. This dissertation takes advantage of the unique

characteristics of written Chinese to provide better understanding of human language processing. Furthermore, it has important implications for visual word recognition of logographic writing systems as Chinese orthography is adapted by a number of East-Asian languages (e.g., Japanese *Kanji*, Korean *Hanja* and Vietnamese *hán tự*). This approach will in return shed light on the respect and extent to which the human language processing mechanism is universal across typologically different languages, and why we process language as we do.

2. Research background

2.1 General knowledge in reading

2.1.1 Basic functions of reading

The language system contains phonological, morphological, semantic and syntactic information. Reading comprehension could be seen as a result of the interaction of these components (e.g., Perfetti & Sandak, 2000). In Friederici and Lachmann's study (2002), they pointed out the processes and components that are specific to reading, compared to auditory processing, are (i) the identification of visual features relevant to defined letters, (ii) the identification of a visual word form, (iii) and trans-coding from orthography to phonology. In a broad sense, reading could be characterized as language comprehension.

The following are the brain regions that were identified to be associated with word reading. The visual feature of letters is processed in contours and the occipital lobe specified to detect line orientation (the curves of the scrip). During reading, the fusiform gyrus (Brodmann Area 37) is activated within the occipito-temporal brain area (Fiebach, Schlesewsky, & Friederici, 2002). The centre part of the fusiform gyrus is taken to be the locus of the visual word form area, that is, a perceptually invariant higher-order orthographic unit is configured from the visual unit (Cohen, Dehaene, Naccache, Lehericy, Dehaene-Lambertz, Henaff, & Michel, 2000). Yet, although this brain region in the fusiform gyrus is activated when reading, it is not reading specific since it is also activated during other visual recognition, i.e., face recognition (Haxby, Hoffman, & Gobbini, 2000) and more generally when skilled experts process specific objects of the category of their specialties (Gauthier, Skudlarski, Gore & Anderson, 2000). For example, written words could be taken as an extension of the notion of a category-specific recognition here, i.e., to see a literate adult as an expert of a category for reading (Fiebach, Friederici, Muller, & von Cramon, 2002).

The phonological processing, the phonological retrieval and the phonemic analysis are associated with the left inferior frontal gyrus and the anterior insula. Interestingly, activations in this region were observed both during pronunciation tasks and lexical decision tasks (Fiebach, Friederici, Muller, & von Cramon, 2002). Fiebach et al. found that for low frequency words and for pseudo-words (i.e., fake words), a increased activation of the superior part of the left pars opercularis was observed when compared to real words. The result suggests that lexical access was mediated by phonological information for the formal word forms. As a result, this area seems to involve in phonological process both during production and perception. The left middle temporal gyrus, which is known to be associated with auditory language processing, has been observed as part of the neural networks of word reading. Above all, activations in this area, associated with the activation of phonological word forms, open the door for lexicon (for details, see Hagoort, Brown, & Osterhout, 1999; Price, Wise, Watson, Patterson, Howard, & Frackowiak, 1994).

In summary, brain imaging studies show that there are no brain areas that are specific to reading only. Moreover, it appears that learning to read is a process of establishing connections between object processing areas in the visual cortex and auditory processing areas in temporal and frontal cortices (Price, Thierry, & Griffiths, 2005). From an evolutionary point of view, reading is a secondary system that has not evolved reading specific mechanisms. Rather, it operates in the brain under other functions.

2.1.2 Variations across languages

The process of learning to read involves a variety of cognitive skills (see Ziegler & Goswami, 2005) and its route is shaped by the features of a given written system (see Bialystok, Majumder, & Martin, 2003). Present studies on word reading show that phonological awareness, morphological awareness and orthographic knowledge are important factors in word reading across different languages, e.g., alphabetic and non- alphabetic languages (e.g., Charlisle, 1995; Foorman, 1994; Ho & Bryant, 1997; McBride-Chang & Ho, 2000; MaBridg-Chang, Shu, Zhou, Wat & Wagner, 2003). Additionally, their importance to word reading varies according to the characteristics of languages (e.g., Deacon, Wade-Woolley & Kirby, 2007, Koda, 2000). In recent years, more evidence on monolingual and cross-lingual reading has suggested that the variation in reading process across languages attributes to different required skills for learning to read in

different languages and orthographies (e.g., Cheung, Chen, Lai, Wong, & Hills, 2001; Gottardo, Yan, Siegel, & Wade-Woolley, 2001; Wang, Perfetti, & Liu, 2005).

2.2 Chinese language and Chinese orthography

Chinese orthography is structurally and informationally richer than most other orthographies. Most words are made up of one to two characters, with some consisting of more (e.g., 3 or 4). It has been suggested that Chinese characters are the smallest meaningful perceptual units (Chen, Allport, & Marshall, 1996). Each a Chinese character consists of a square pattern of strokes (Hoosain, 1991; Chen, Allport, & Marshall, 1996). A stroke pattern is a single functional unit that cannot be decomposed to smaller units. Individual strokes have no meaning in isolation whereas many of these stroke patterns (often referred as “simple” characters or single bodies; see Huang & Hu, 1990; Chen, Allport & Marchall, 1996; Hsiao & Shillcock, 2006) also function as characters. Chen, Allport and Marshall (1996) further defined these stroke patterns as lexical radicals (also known as “*Bu Shou*” in an index system of Chinese dictionaries). In modern Chinese, there are currently 214 Bu Shou listed in a traditional Chinese Dictionary (Mandarin Promotion Council, Ministry of Education, R.O.C., 2000, as cited in Hsiao & Shillcock 2006). Each character contains one lexical radical to imply some aspects of its meaning and the rest of the character (it could be non-radical components or another lexical radical) usually indicates the pronunciation of the characters. In some cases, there can be two listed lexical radicals in one character. However, there can only be one dominant lexical radical when the other only serves as a partial cue of the pronunciation (e.g., the rhyme) and is often referred as a phonetic radical. In sum, Chinese characters are made up of square stroke patterns by means of a complex regularity.

According to Chinese etymology, Chinese characters can be roughly generalized into four different types: pictographs, indicatives, ideographs and semantic-phonetic compounds (see also



Figure 3: an example of pictographic (left) and indicative (right) characters

Hsiao & Shillcock, 2006). Pictographs and indicatives are referred to as simple characters. Figure 2 has shown an example of pictographic and indicative characters. The pictographs are characters portray the form of objects. The left character in Figure 2 means a “heart.” The form of the character reflects the shape of the human heart. The indicatives are modifying pictographs (one pictographic character with an indicating sign). For instance, the right character

in Figure 2 means “blade” and the character is originally modified by a pictographic character, “刀”, means “knife”.

Figure 3: an example of ideographic (left) and semantic-phonetic compound (right) characters

On the other hand, ideographs and semantic-phonetic compounds are more complex compound characters. Figure 3 displays an example of ideographic and semantic-phonetic compound characters. An ideography is a compound character whose meaning is indicated by its components. For example, the left character in Figure 3 is composed by two “trees” (木) and means “the forest”. The last type of Chinese character is semantic-phonetic compounds which are the most common type, with one radical to indicate some aspects of its meaning and the other to indicate the pronunciation. For instance, the right character in Figure 3 is pronounced as / xian4/ in pinyin and means “the oak tree.” The character consists of a semantic radical, 木, which means a “tree”, and a phonetic radical, 象, pronounced as /xian4/. Most Chinese characters consist of multiple components (radicals). According to Li and Kang (1993), semantic-phonetic compounds comprise approximately 81% of the 7000 frequent characters in a standard Chinese dictionary. Particularly, the most common configuration is to have the semantic component on the left, and the phonetic component on the right.

Chinese character recognition is known as a difficult task in visual word recognition due to its large character set (approximately 4574 Chinese characters that compile most Chinese words; Tan, Hoosain, & Peng, 1995), and the high visual complexity of Chinese characters. In particular, there are many similar character patterns which might contain completely different meanings. In the respect of learning, the beginning learners need to start from the simple and easy ones. During the process of learning, readers may develop different cognitive strategies according to the level of complexity and difficulty of characters (see Huang & Ma, 2006). It has also been demonstrated that the structure of the characters and the reader’s knowledge (e.g., educational background) and familiarity with the character influences oculomotor behavior in reading (Sun, 1993). For example, the phonetic radical were shown to receive more attention when the reader encountered an unfamiliar phonetic compound (Sun & Feng, 1999). Thus, the ability to analysis the distinct structure of Chinese orthography plays an important role at the process of reading and recognizing characters.

In addition, the complexity of Chinese characters varies in the way they differ in their manner of construction, i.e., regularity and consistency. As mentioned previously, phonetic compounds are the most common configuration in Chinese and they contain both phonological

	Character	Phonetic radical
1	燈 'deng'	登 'deng'
2	湘 'xiang'	相 'xiang4'
3	江 'jiang'	工 'gong'
4	調 'tiao4'	周 'zhou'

Figure 4: examples of phonetic compounds with different levels of regularity

information and semantic information in different components. However, its regularity differs in how well the phonetic radical reflects the pronunciation of the character. For instance, as demonstrated in Figure 4, the reliability of phonological cues is variable. The first set in Figure 4 is an example of regular characters. The pronunciation of the character and its phonetic radical are precisely identical (share the same pronunciation and the same tone). The second set in Figure 4 is an example of semi-regular characters where the pronunciation of the character and its phonetic radical are the same but with different tones. The third and fourth sets in Figure 4 are categorized as irregular characters. However, while for the fourth set the character and its phonetic radical are pronounced fundamentally differently, for the third set, the character and its phonetic radical still share the same rhyme (Hsiao & Shillcock, 2006 as cited in Lee, Shillcock, & Obregon, 2007).

Within the respect of character consistency, phonetic compounds are considered as consistent when characters with the same phonetic radical share the same pronunciation. Figure

成	城	誠
'cheng'	'cheng'	'cheng'

Figure 5: examples of consistent characters

5 is an example of consistent phonetic compounds. Likewise, a phonetic radical of consistent characters is categorized as consistent as well (Fang, Horng, & Tzeng, 1986; Feldman & Siok, 1999). Additionally, in Chinese, there are approximately 800 phonetic radicals and around 38% of them are regarded as consistent phonetic radicals (Taylor & Taylor, 1983; Zhou, 1978).

It has been reported that character regularity and consistency have an influence in the processing of Chinese character recognition. As reported by Hue (1992), regular phonetic compound characters were named faster than irregular characters, and consistent characters were in the same trend as well. In particular, it was found that character frequency modulated the regularity effect. A regularity effect was only obtained in low frequency characters whereas a consistency effect was obtained for both high and low frequency characters (Fang, Horng, & Tzeng, 1986). Moreover, in a more recent study, Hsiao and Shillcock (2006) examined phonetic compounds, Chinese two character words, with a left-right structure. As mentioned earlier, the most common configuration of phonetic compounds is to have semantic radical (S) on the left and the phonetic radical (P) on the right (SP characters). However, there are also a number of characters whose configurations are the opposite (Phonetic- left; semantic- right: PS characters; a

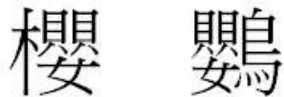


Figure 6: an example of SP (left) and PS (right) characters

less common type). Figure 6 shows an example of SP and PS characters. The left character (SP) in Figure 6 means 'cherry tree' and pronounced as /ying/ in pinyin. The right character (PS), on the other hand, means 'parrot' and pronounced also as /ying/. The shared component indicates the pronunciation. The semantic component in the SP character indicates the character

is something to do with a 'tree', whereas the semantic component in the PS character indicates the character is something to do with a 'bird'. Thus, based on this distinctive structure, Hsiao and Shillcock surveyed the regularity of SP and PS character in a computational model of Chinese character recognition. A significantly higher percentage of regularity in pronunciation of SP characters was reported. Furthermore, SP characters tend to have lower character frequency than PS characters. High variability was demonstrated especially on the right of the characters. Therefore, among all Chinese phonetic compounds, computational modeling evidence indicated that the right side of the character is more informative than the left side of the character.

Overall, the structure of Chinese orthography provides opportunities to investigate different aspects of reading in ways that are not available in alphabetic orthographies. For instance, there is a long running debate about the issue of direct orthographic-to-semantic processing in the right hemisphere of the brain. Interestingly, in Chinese, phonological mediation in lexical access might not be necessary in principle, as the semantic radical would indicate some aspects of the semantics of the character. According to Tzeng, Hung, Cotton and Wang (1979), the right visual field-left hemisphere (RVF-LH) enjoys an advantage in processing alphabetic orthographies,

while left visual field-right hemisphere (LVF-RH) has a superiority effect in the recognition of logographic orthographies. This hypothesis is based on the plausible interactions of hemispheric difference and orthographic features of alphabetic and logographic languages. A cerebral orthography-specific localization hypothesis was thus proposed to claim for this observation. In research of Japanese Kanji (a graphic-based script) and Kana (a phonetic-based script), Sasanuma (1974; 1977) presented evidence from clinical research to show that Japanese aphasic patients exhibited different symptoms in using Kanji and Kana scripts which may be selectively related to type of aphasic disorders. This finding was in line to support the function-specific property of the two hemispheres.

However, some argued that the hemisphere differences found here can only suggest a task-specific feature of our cerebral hemispheric processing rather than an orthographic-specific feature (Tzeng, Hung, Cotton, & Wang, 1979). Indeed, there is still no direct or strong evidence to support radically different cognitive processes in reading alphabetic and logographic orthographies. This hypothesis has been critically re-examined in research of both Chinese and Japanese reading (e.g., Paradis, Hagiwara, & Hildebrandt, 1985; Flores d'Arcais, 1992; Yan, Tian, Bai, & Rayner, 2006). Overall, reading Chinese orthography is a comprehensive task. Despite there might be some differences in cognitive processes across orthographies, there is no obvious evidence to show radical violations in terms of universal psycholinguistic principles. For example, as English learners must learn letters in order to read, readers of Chinese need to first learn the characters that are used to represent speech. Yet, languages vary in the consistency and regularity of the mapping between letters (or characters), sounds and meaning. According to psycholinguistic grain size theory (Ziegler & Goswami, 2005), there were different processing strategies of skilled reading in different orthographies that might be related to different developmental constraints in different writing systems and with experience, readers could develop a strategy that is most efficient in respond to the feature of the writing system. In general, regularity effect and consistency effects are both found in alphabetic and non-alphabetic languages (for studies in Chinese, see Fang, Horng, & Tzeng, 1986; Lee, Tsai, Huang, Tzeng, & Hung, 2006; Lee, Tsai, Su, Tzeng, & Hung, 2005; for studies in English, see Cattell, 1886; Reicher, 1969; Wheeler, 1970).

To sum up, whether the hemisphere differences found in processing alphabetic and logographic scripts can contribute to a orthography-specific feature, the studies discussed above still suggest that our two hemispheres have different processing preferences due the different

prosperities within and between orthographies (for a further discussion, see the section *the cognitive processes underlying the reading of Chinese characters*). Researchers into the processing of Chinese characters have been interested in the issues of how independent are the semantic processing and the phonological processing, and how and when do these different types of information come together to define the whole character. As introduced earlier, Chinese characters are very compact, therefore they allow us to investigate processing occurring in areas of the visual field that are more constrained than is possible with longer alphabetic words. This is an issue worth pursuing because reading researchers have been interested in the precise projections from different parts of the retina, particularly the fovea, the relatively small part of the retina that is involved. This critical issue will be discussed further in the section *visual pathways*.

2.3 Cognitive processes underlying the reading of Chinese characters

2.3.1 The Chinese character-word association view

The Chinese character- word dissociation hypothesis under the laterality patterns proposes that the left hemisphere is dominant in process of alphabetic languages, whereas the right hemisphere might be a dominant hemisphere in the process of non-alphabetic languages (e.g., Beaumont, 1982; Binder, Rao, Hammeke, Frost, Bandettini, Jesmanowicz, & Hyde, 1995; Howard, Patterson, Wise, Brown, Friston, Weiller, & Frackowiak, 1992; Price, Wise, Watson, Patterson, Howard, & Frackowiak, 1994).

In addition, it has been suggested that the right hemisphere has an advantage in processing single Chinese characters due to its orthographic structure. Despite the variation in complexity of Chinese characters, the Chinese character is composed by a number of strokes that are packed into a square shape. The character as a whole is one meaningful perceptual unit. Within single character identification, the right hemisphere is presumed to be more involved than the left hemisphere since the right hemisphere is specialized at holistic and spatial processing (Bryden, 1982; Ellis, Young, & Anderson, 1988; Jonides, Smith, Poeppe, Awh, Minoshima, & Mintun, 1993; Kosslyn, Alpert, Thompson, Maljkovic, Weise, Chabris, Hamilton, Rauch, & Buonanno, 1993). Due to that a Chinese word often contains two different characters (or radicals), its identification involves the recognition of each character and their assembly process (Tan & Perfetti, 1999). In this process, the left hemisphere functions as a temporal, sequential analyzer.

In studies of Japanese Kanji and Kana, neuroimaging evidence showed a right hemisphere advantage for processing Kanji (graphic based script) and a left hemisphere advantage for processing Kana (phonetic based script). Hence, the feature of writing systems appears to have an influence on cerebral lateralization. Moreover, studies with American Sign Language (ASL) supported the notion that languages may have different processing requirements. Research showed that ASL is mainly associated with right hemisphere activations, in addition to left hemisphere activation (Neville, Bavelier, Corina, Rauschecker, Karni, Lawani, Braun, Clark, Jezzard, & Turner, 1998). Following research showed evidence for left lateralization in recognition of two character words in Chinese (Fang, 1997). However, in studies using the interaction of visual hemifields to investigate the recognition of single characters, the evidence for right lateralization is not so obvious. The results suggested either no difference for the two hemispheres or a left hemispheric advantage (e.g., Besner, Daniel, & Slade, 1982; Fang, 1997; Leong, Wong, Wong, & Hiscock, 1985).

2.3.2 Studies in contrast to Chinese character-word association hypothesis

In Chee, Tan and Thiel's study (1999b), he investigated Chinese character processing with neural imaging techniques and reported strong activations in the left hemisphere, bilateral occipital and bilateral parietal regions. Thus, Chee et al. found no evidence for right hemisphere dominance. Furthermore, clinical studies of selective language impairments also indicate that Japanese Kanji and Kana are processed by similar neural pathways and the difference in features of the two scripts may provide no constraints in cerebral specialization (for a detailed discussion, see Koyama, Kakigi, Hoshiyama, & Kitamura, 1998).

Above all, the Chinese character-word dissociation view might seem to over-emphasize the visual-orthographic property of Chinese characters. Chinese writing system is a morphemic system that is based on the graphic forms and the meaning they stand. In other words, despite the difference in features with alphabetic languages, Chinese characters are still pronounceable units. In cognitive research on Chinese reading, the attributes of its visual-orthographic, phonological and semantic component are merely equal (Chua, 1999; Perfetti & Zhang, 1995; Pollatsek, Hyona, & Bertram, 2000; Tan, Hoosain, & Siok, 1996; Ziegler, Tan, Perry, & Montant, 2000). Therefore, the left hemisphere should, presumably, be relevant to the activation of the single character's phonological and meaning components due to its analytic, semantic and phonetic processing preference. In sum, the visual recognition of Chinese characters engages activations

and integrations of the large-scale cortical neural systems that are accountable for visual-orthographic, phonologic, and meaning attributes (Bressler, 1995; Kock, & Davis, 1994).

2.3.3 Beyond the Chinese character-word association hypothesis: character processing

In light of previous studies, we have learned more about the universal rules and also the possible differences across languages. More alternate views are emerging to broaden our understanding of the process of language, specifically, in addition to well-established studies in Indo-European languages, the surging research in the logographical languages have contributed to the understanding of psycholinguistic mechanisms in a wider perspective.

Within the topic of the cognitive processing of Chinese language, it seems that it is important to further explore the critical implication of Chinese distinct structure at the cognitive processing. Research has shown that, in reading Chinese, besides the lexical level processing, the radical level processing is playing a crucial part in skilled reading. As mentioned briefly earlier, research has demonstrated that the minimum units of Chinese orthography are strokes and the minimum perceptual units in are the stroke patterns or radicals (Chen, Allport, & Marshall, 1996). It has been further pointed out that stroke analysis and component decomposition are crucial in the primary stage of visual word recognition in Chinese (Huang, 1986; Taft & Zhu, 1997; Tan, Hoosain, & Peng 1995). In particular, although there are two different type of radicals (phonetic and semantic radicals), the processing of phonetic radicals does not differ fundamentally from the processing of semantic radicals. In other words, sub-lexical processing of the phonetic component involves not only phonological processing but also extends to character level processing (Zhou & Marslen-Wilson, 1999). Similar to the obvious semantic activation of semantic radicals (transparent semantics), the semantic activation of phonetic radicals appears to be inevitable and sometimes even interferes the processing of the whole character. Several studies demonstrated that the speed and accuracy of Chinese character identification could be affected by the properties (i.e., frequency and position) of the components (i.e., semantic and phonetic component) of the whole characters (Perfetti, Charles, Zhang, & Sulan, 1991).

Thus, it indicates that the combinability of the radicals (the number of combinations of a radical to form characters; see Feldman & Siok, 1999) could have an influence in Chinese character recognition (i.e., radical level processing interferes lexical level processing). In particular, the position of the radical and its combinability could affect character decisions (the

combinability of the right radical have an effect when the combinability of the left radicals does not; see Taft & Zhu, 1997). As mentioned in Hsiao, Shillcock and Lavidor's study (2006), this facilitatory effect of semantic radical combinability could be compatible with the neighborhood effect in English (the identification of words with many lead neighbors, i.e., words that share the same initial letters) is facilitated compared with words with few lead neighbors). In the study, by using of parafoveal cues, they examined the efficiency of phonological cues in the lateralized parafovea to investigate semantic radical combinability effect specifically in SP characters (the most frequent structure of phonetic-compounds). The left parafoveal vision was found to be more helpful in semantic judgments of characters with smaller number of combinability than characters with larger number of combinability. The results indicated that the semantic radical with relatively small combinability are more informative in terms of the extraction of the semantic information of characters. It may be due to the fact that fewer characters share that semantic radical thus the semantic content of the semantic component was more identical. On the other hand, for semantic characters with relatively larger number of combinability, the phonetic component of the character plays a more important role in the identification of the whole characters.

However, research obtained inconsistent results of how radical combinability facilitates character decisions. When Feldman and Siok (1999) examined this confounded relationship between radical types and positions, they found that only the semantic combinability of left radical affected character decisions. Overall, the effect of semantic radical combinability on semantic judgment task is relatively consistent when the relationship of radical combinability and its position still shows inconsistencies. Besides the character combinability effect, characters with better semantic radical combinability were also found to enjoy an advantage in character categorization as well as character semantic transparency judgment. Further interactions between semantic combinability, consistency and transparency were also found in Chen and Weeks's study (2004).

Above all, Chinese character recognition may involve not only the lexical level processing but also the radical level processing. Radicals and their attributes such as semantic combinability, semantic transparency and semantic consistency are all important factors which have an influence in the process of reading in Chinese.

2.4 Visual pathway

2.4.1 Contralateral pathways, foveal splitting and brain lateralization

The human fovea is the part of the eye, located in the center of the macula region of the retina, which is responsible for fine-grained, focal visual processing (often referred as foveal vision). For example, when reading, the fovea is where the fixed word is projected onto. However, the processing detail of how the fovea projects visual information to both hemispheres is still yet reached to a general consensus. Currently there are two main hypotheses to address the issues of foveal processing of the visual information. The *bilateral representation hypothesis*, a more traditional account, suggested that the visual information is projected simultaneously to both hemispheres. Therefore, when the visual stimulus falls within the fovea, no inter-hemispheric transfer would be required to read a word. In contrast, *split fovea hypothesis*, supported by recent anatomical and behavior studies, suggested that the fovea is anatomically and functionally divided down the middle and even though both eyes project to both hemispheres, the visual pathways from the retina to the cortex may differ in how well they can project information. In fact, recent evidence implies that contralateral *pathways* (e.g., left eye to right hemisphere) are better at projecting information than *ipsilateral pathways* (e.g., right eye to right hemisphere) (Tossy, Werring, Plant, Bullmore, Miller, & Thompson ,2001). Therefore, each half of the fovea initially projects contralaterally to a different cerebral hemisphere. In other words, all visual information that originates to the left of fixation projects initially to the right cerebral hemisphere while all visual information that originate to the right of fixation projects first to the left cerebral hemisphere. This pattern of projection happens in each eye. Following on this account, these possible differences in the visual pathways allow us to pick apart the processing of the right and left parts of a word or character.

According to the split fovea hypothesis, when the eyes are fixated on a printed word, semantic information about the letters falling to the left of fixation is projected initially to the right cerebral hemisphere while semantic information about the letters falling to the right of fixation is projected to the left cerebral hemisphere (where the language domain hemisphere is for most people, with some exceptions to have the language domain hemisphere at the right cerebral hemisphere of the brain). The two parts of the word must be combined in order to achieve word recognition. This has an important implication in reading since a split fovea affects the reading of words at fixation. If the possibility of such an effect exists, it should not be ignored by studies in

cognitive, computational and neural models of reading (for a comprehensive review, see Ellis & Brysbaert, 2010). Moreover, despite at this stage being controversial, a well-balanced amount of evidence has demonstrated the potential of the plausibility of the split fovea hypothesis. Furthermore, regardless of there are still some inconsistent results under this pattern, the split fovea account may lead us in the right direction in understanding more about reading processes since this exact foveal splitting thus implies a key anatomical constraint on reading. For example, the integration process from the left and right visual field and in the left and right hemisphere is currently the main focus.

Previous studies, investigating the processing of foveally presented stimuli, have found hemifield differences during visual word recognition (Brysbaert, 2004; Shillcock, Ellison, & Monaghan, 2000). A contralateral effect was revealed on reaction times driven by the first and last part of the words which could be reasonably explained by different processing styles of the two hemispheres. Other effects such as the optional viewing position effect (Brybaert, 1994), the word length effect (Lavidor, Ellis, Shillcock, & Bland, 2001), case alternation effects (Ellis, Brooks, & Lavidor, 2005) and the orthographic neighborhood effect (Lavidor & Walsh, 2003), are all in the line to support that split fovea could affect natural reading.

Moreover, within this account, the foveal processing could also be extended in ways to help us understanding the cross-linguistics difference in cognitive processing since visual and linguistic information skew differently with and between orthographies. In reading alphabetic language, the effect would include all the letters in a centrally fixated word that falls within the fovea. It has been well-established that in a normal reading condition, some words are skipped, whereas most words are fixated. In natural reading conditions, when a word is fixated, the fixation point would naturally fall around one-third of the way onto the printed word (O'Regan & Jacobs, 1992; Rayner, 1998). According to the split fovea hypothesis, those letters in a centrally fixated word that fall to the right of fixation will be projected initially to visual areas in the left hemisphere (where the phonological information stored, in most cases) while those letters that fall to the left of fixation will be projected first to visual areas in the right hemisphere. Since word recognition will include access to the word's meaning (semantics) and its spoken form (phonology), the two parts of the word will need to be combined in order to complete identification, which would presumably involve the transfer of those letters projected to the non-dominant hemisphere across the corpus callosum to the language-dominant hemisphere from which word recognition can proceed. Therefore, additional computing process is required. In

English word reading, an exterior letter effect (i.e., both the first letter and the last letter enjoy a privilege position in visual word recognition) was obtained which reflects the functional and anatomical role of spilt-fovea model in visual pathways (Shillcock, Ellison, & Monaghan., 2000; Shillcock & Monaghan, 2001).

However, from a cross-linguistics point of view, since orthographies differ in its structure, regularity and consistency in mapping onto visual and semantic information and often have an uneven distribution of information (e.g., in Chinese two character words, the right side of the character is more informative than the left side of the character; see Hsiao, & Shillcock, 2006), the spilt-fovea model could result in further implication in reading Chinese characters due to its distinctive structure (for a detailed profile, see the section *Chinese language and Chinese orthography*). Following a similar model, Hsiao and Shillcock further applied the spilt-fovea model to investigate Chinese phonetic pronunciation. Unsurprisingly, the regularity effect was obtained and an interaction between character regularity and character frequency was found in Chinese character recognition which is consistent with the studies in English.

As introduced in an earlier section, Chinese orthography is very compact. Most two character word consists of one component with a cue of the meaning of the character (i.e., the semantic radical) and another component with a cue of the pronunciation (i.e., the phonetic radical). Interestingly, under the spilt-fovea architecture, the two radical would initially be processed in a different hemisphere. Hsiao, Shillcock and Lee (2007) therefore examined the model by using two character words with a S-P structure (i.e., the semantic radical on the left and the phonetic radical on the right; the most frequent pattern in Chinese orthography) and two character words with a P-S structure (i.e., the semantic radical on the right and the phonetic radical on the left). The words were deliberately presented within foveal vision. The experiment was to present the target characters and the comparison characters respectively. The task was to judge whether they share the same pronunciation when EEG responses were recorded simultaneously. The EEG responses have shown that a stronger N170 effect was found in the left hemisphere than in the right hemisphere for the characters with the phonetic radical to the right of fixation and vice versa for the characters with the reversed structure.

The results indicated that the strength of the N100 responses was modulated by the position of the phonetic radical. Under the bias of spilt fovea model, the phonetic radical presented to the right of fixation was projected directly to the left hemisphere where is the language dominant hemisphere that stored all the phonological information. As a result, the phonological content was

extracted readily and the processing was facilitated. On the other hand, the phonetic radical presented to the left of the fixation was projected to the right hemisphere and was required extra transformation across the corpus callosum to the left hemisphere to encode its phonological content. It explained why the EEG response to the phonetic radical of the character was stronger when that component fell to the right of fixation rather than to the left. Thus, the split model successfully addressed facts of the phonetic radical positions and the skewed distribution in Chinese left-right phonetic compounds.

Overall, while the results in alphabetic languages still remains variable, results of studies in Chinese character recognition is relatively consistent due to its distinct orthographic feature that is relatively convenient for the examination (i.e., S-P and P-S characters). The split foveal hypothesis is further supported by studies in Chinese characters recognition from TMS examinations and ERP studies (see Hsiao, Shillcock, & Lavidor, 2006; Hsiao, Shillcock, & Lee, 2007, for a detailed discussion). These findings suggest that functional foveal splitting may be a universal processing constraint on reading, and this anatomical constraint can further interact with the asymmetric function in the two hemispheres.

In addition, it may be reasonably argued that fixating exactly on the middle of the character merely occurs in the controlled laboratory condition at the initial stage of visual recognition and the split fovea model may not have genuine implication in natural reading condition. However, if the split fovea claim provides a better architecture of foveal processing of visual stimuli, the implication of cognitive, computational and brain-based model of reading is necessary to be explored further. The important implications are how and when the information of both eyes (beyond the fovea) is integrated and what might be the consequence if the corpus callosum fails to transfer information. Furthermore, even if the split fovea effect could be a universal constraint on reading, it could still appear in different forms across languages due to the variation of the orthographic feature. To explore its plausible implication would contribute to the development of the comprehensive knowledge of why and how a language is working the way it is.

Brian lateralization

In order to read fluently, humans do not only have to use the two eyes to perceive information but also need to process the information with the brain. The human brain can be delineated by the median line to the right and left cerebral hemisphere in which the two hemispheres are connected by the *corpus callosum*. The existence of anatomical and functional hemispheric difference has

been supported by a strong amount of evidence (Gazzaniga, 2000). It has been reported that the right hemisphere has a predominate advantage for *coarse semantic coding* (approximate decoding in any domain of representation; in the domain of language: prosody, pragmatic and contextual semantic information). Conversely, the left hemisphere has been claimed to involve more *in fine semantic coding* (exact coding on a single interpretation; in the domain of language: grammar, vocabulary and literal information). In other words, while the right hemisphere is suggested to be more engaged in making remote semantic or pictographic associates, the left hemisphere is more connected to making fewer but closer associates (Beeman, 1998; Beeman & Bowden, 2000).

The hemispheric difference in processing styles of decoding semantic information was demonstrated in studies investigating semantic relations of words by presenting stimuli to the right visual field-left hemisphere or left visual field- right hemisphere (RVF-LH vs. LVF-RH) (Beeman, 2005). Beeman, Friedman, Friedman and Perez (1994) found that the left hemisphere enjoyed a better advantage when priming effects were induced by a direct entry of the semantic prime while on the other hand the right hemisphere was benefited from summation of multiple activations (semantic activation were accumulated more easily when the summation of primes was presented to LVF-RH).

Therefore, the different hemispheric processing styles and the split foveal effect together could have profound implications in the domain of reading, especially in the reading of Chinese. The distinct structure of Chinese orthography and the skewed distribution of linguistic information in different types of characters allow us to explore the hemispheric processing preferences in reading (e.g., Hsiao & Shillcock, 2004, 2005a, 2005b). Moreover, we can learn more about the underlying cognitive mechanisms of the visual field integration for which our visual perception might be influenced by the different processing style of the two hemispheres and how the visual information was sent to the both hemispheres. For example, we might be able to read faster or name the words more accurately when the words are presented to the RVF-LH than to the LVF-RH. On the other hand, the right hemisphere might perform better in rejecting semantically unrelated images, while the left hemisphere might perform better in rejecting semantically unrelated words. Thus, this interaction of hemispheric processing preference and the inter-hemispheric pathways could potentially attribute to the cognitive representation of the visual information, especially regarding the processing of symbolic carriers such as words.

2.4.2 Binocular rivalry

Binocular rivalry is a perceptual phenomenon which occurs when viewing a different visual stimulus with each eye, we experience alternated perceptions between the visual stimuli. More specifically, binocular rivalry happens when neurons encoding two dissimilar stimuli that engages in reciprocal inhibition (Blake, 1989). During the process, the processing of one stimulus inhibits the processing of the other stimulus, therefore yielding consciousness of one ‘*dominant*’ stimulus at any moment and suppressing the other ‘*secondary*’ stimulus. The dominant status switches between stimuli because when neurons encoding the dominant stimulus weaken their activity and the inhibition they can exert, neurons encoding the suppressed stimulus recover from adaptation until next time the balance of activity reverses. This process results in an alternation in consciousness. In other words, different information projected onto each retina compete for awareness (e.g., compete to be the ‘*dominant*’ stimulus) which leads to parts of the information projected onto the retina being perceptually suppressed. The underlying mechanisms driving the selection of information is the reason why this phenomenon attracts researchers’ interest.

There are two conflicting theories to address the nature of the processes of the selection of information. The *eye-rivalry theory* proposes that binocular rivalry involves only low-level processing in visual pathway, i.e., the competition happens at an early stage of visual processing between monocular visual channel to determine which eye will gain dominance (Blake, 1989). On the other hand, the *stimulus rivalry theory* (also referred as image rivalry) proposes that binocular rivalry is a higher level process that occurs between representations of visual stimuli, i.e., the competition happens at a late stage of visual processing between hemispheres. Both theories are supported by functional imaging and psychological studies (for studies in favor of eye-rivalry theory, Polonsky, Blake, Braun, & Heenger, 2000; Tong & Engel, 2001; Blake & Fox, 1974; Blake, Westendorf, & Overton, 1980; for studies in favor of stimulus rivalry, Logothetis, 1998; Kovacs, Papathomos, Yang, & Feher, 1996). Furthermore, a general consensus that both theories can co-exist is emerging (e.g., Blake & Logothetis, 2002; Silver & Logothetis, 2007). In particular, some studies propose that rivalry suppression may occur at several stages during the visual processing (a multistage model; e.g., Freeman, 2005; Lee & Blake, 2004; Nguyen, Freeman, & Alais, 2003; Wilson, 2003). In fact, a considerable amount of research has shown that the perception of the dominant stimulus during rivalry could be influenced by the suppressed stimulus in a non-random fashion (Andrews & Blakemore, 2002; Carlson & He, 2000; Pearson & Clifford, 2005; Treisman, 1962). In particular, Pearson and Clifford (2005) reported that, in the

completion of orientations during rivalry, the suppressed orientation systematically biases the perception of the dominant orientation. Moreover, in Treisman's study (1962), the results showed that, during rivalry, a perception that combined the perception of the two completing stimuli may occur.

Yet, the results of studies investigating the level of binocular rivalry in visual processing are inconsistent. Some studies show selective suppression effect for both high and low level features (Alais & Parker, 2006; Athorp, Wenderoth, & Alais, 2009; O'Shea & Crassini, 1981), while others did not (Nguyen, Freeman, & Wenderoth, 2001). However, it should be noted that previous studies argued the nature of rivalry suppression is a nonselective process based on conflicting results that were observed by using rival stimuli that were consistently harder to detect in suppression than in dominance (e.g., Fox & Check, 1966, 1968; Wales, & Fox, 1970). The eye-rivalry theory was based on those evidences to suggest that an eye is insensitive to all visual input during suppression, not just the suppressed stimuli. Hence, the idea of nonselective suppression was formed (Blake, Westendorf, & Overton, 1980). Although past studies have reported evidence demonstrating that all visual input to the suppressed eye has an equal chance to suffer from suppression, it does not necessarily lead to the definite conclusion that all visual input are suppressed to the same extent. Recent studies reported that the application of rapid switches of stimuli between the eyes resulted in slow rivalry which shows that the alternated perception may not have been a result of rivalry between the eyes (i.e., monocular competition model) but rather a result of competitions between two image representations (i.e., binocular competition model) (Logothetis, Leopold, & Sheinberg, 1996; Silver & Logothetis, 2007).

Continuous flash suppression paradigm and binocular rivalry

The binocular rivalry therefore provides a unique opportunity to investigate the processing details in the phase of visual processing and its relation to the mental representation of the external world. Continuous flash paradigm (CFS paradigm; Tsuchiya & Koch, 2005; Fang & He 2005) is a recent technique using binocular rivalry to investigate visual awareness. As in binocular rivalry (two dissimilar stimuli being presented to each eye simultaneously), this technique employs dichoptic stimulation. In this paradigm, a target stimulus (an image or a word) is presented to one eye and a high contrast dynamic noise mask is presented to the other eye at the same time. The target stimulus cannot be consciously detected at first because of the prolonged inter-ocular suppression intentionally caused by the high contrast dynamic noise masks. The prolonged suppression time gives us baselines to examine the properties of the target stimuli and

its influence by measuring the duration to recover from the inter-ocular suppression (Tsuchiya, Koch, Gilroy, & Blake, 2006). The technique has recently been used constantly in studies on implicit processing. Previous studies using this paradigm have successfully demonstrated that high level processing was also occurred even when the visual stimulus were still invisible to our consciousness (e.g., Tsuchiya & Koch, 2005; Hong & Blake, 2009; Maehara, Huang, & Hess, 2009).

Most of the studies used this paradigm to investigate semantic processing of pictures or images such as facial expressions (emotional faces were detected faster than neutral faces; see Jiang & He, 2006; Yang, Zald, & Blake, 2007; Jiang, Shannon, Vizueta, Bernat, Patrick, & He, 2009), and tools (see Fang & He, 2005; stronger responses to images of tools than of human faces). However, recently more studies apply this paradigm to investigate language properties (e.g., word forms and meanings). A recent study using the CFS paradigm to investigate semantic priming effects found that semantic priming could occur even with an invisible prime (i.e., invisible due to the inter-ocular suppression; Costello, Jiang, Baartman, McGlennen, & He, 2009). This finding provided evidence that semantic information could be processed and represented without the involvement of consciousness. Jiang, Costello and He (2007) also found that it took unrecognizable words (i.e., nonsense-words) a longer time than recognizable words (i.e., real words) to be released from suppression. Another very recent study (Yang & Yeh, 2011) also employed this paradigm to investigate implicating processing under the phrase of suppression. Yang and Yeh (2011) used words with emotional context as variable and they found that it took negative words a longer time to be released from suppression. The result is consistent with Costello et al.'s finding and demonstrated that semantics could be accessed even under inter-ocular suppression.

Past studies also have used binocular rivalry to investigate whether the semantic information have an influence on the predominance of binocular rivalry. Previous studies used binocular rivalry to investigate whether semantic information in particular is able to affect the predominance of binocular rivalry. Rommetveit, Toch and Svendsen (1968a; 1968b) found that a pair of semantic related words was appeared to be more seeable by the observers than a pair of semantic unrelated words while under the condition of rivalry. The result suggested that semantic information could potentially have an effect of predominance during binocular rivalry. However, Blake argued, in a later study (1988), that he found no semantic influence of predominance during rivalry by using pairs of normal text and nonsense text. Thus, he claimed that no semantic

information could be extracted during binocular rivalry. While studies in binocular rivalry showed inconsistent results in semantic extraction during rivalry, the CFS paradigm might allow us to explore a more genuine effect of semantic information might have on visual awareness since the target stimuli would be competing with the high contrast noise mask instead of competing against each other. The suppression of different stimuli could be used as a measurement scale to analyze the properties of the target stimuli and the size of the effect of those properties more precisely.

This dissertation thus employed the CFS paradigm to examine the issue of the extraction of the semantic information during rivalry suppression in a similar vein but in a wider scope. As discussed earlier, this CFS paradigm takes advantage of binocular rivalry to explore the automatic (unconscious) visual information processing. We investigated the influence of different types of Chinese characters on inter-ocular suppression. Not only the lexical properties (character frequency) were concerned but also the structure of the character (character complexity) was also in the range of investigation. As the Stroop effect¹ (Stroop, 1935) suggested, an advanced or skilled reader could process word recognition implicitly and automatically. Due to the unique structure of Chinese orthography, the orthographic and feature level might be able to lead to different processing speeds. It provides us not only opportunities to examine whether the characters can be processed under inter-ocular suppression but also a chance to take a closer look at the cognitive processing underlying reading in Chinese.

3. Experiment

3.1 Method

3.1.1 Participants

Twenty (Ten male and ten female) native Mandarin Chinese readers with normal and corrected-to-normal vision, fully right handed, were recruited from the University of Edinburgh. Their age were ranged from 23 to 36 years. All participants were native traditional Mandarin readers and finished their first degree in Taiwan. All participants were naïve to the purpose of the experiment and were paid for the participation in the study. All participants signed an informed

¹ Stroop effect: when the color of the ink is not matched with the color word itself, it leads to slow naming speed or error prone in naming the color. For example, saying blue when the word *green* is written in blue ink.

consent form in accordance with the code of Ethics and Conduct of the Ethic Committee of British Psychological Society. Ethical approval was obtained from the School of Psychology, Philosophy and Language Science Ethics Committee.

3.1.2 Apparatus and stimuli

Stimuli were eighty Chinese characters. All characters were carefully selected by character complexity and character frequency. Each group (simple/ complex/ high frequency/ low frequency) contained 20 stimuli. Character frequency was controlled according to the dictionary of Chinese character variants edited by Ministry of Education, R.O.C (2000; <http://dict.variants.moe.edu.tw/> retrieved from May 2011). Character complexity was measured by the number of strokes. Characters with 1-6 strokes were categorized as simple characters (M=3.6) whereas characters with 14-24 strokes were categorized as complex characters (M=18.2). Stimuli were generated with 32bit MATLAB and presented on an EyeLink II head-mounted eye tracker with a resolution of 1024 x 768 pixels using the Psychophysics Toolbox extensions. The monitor was displayed with a viewing distance of 135 cm.

3.1.3 Experimental design

The experiment included two within-subject variables: character complexity (simple/ complex) and character frequency (high-frequency/ low frequency). Gender was manipulated as a between subject variable (male/ female). Their tasks were to click the mouse as soon as they saw the stimuli appeared through the noise mask and to report as accurate as possible which character they saw. The reaction time (RT) was recorded as the dependent variable. Stimuli were presented in a standard print font, each measuring approximately $2 \times 2 \text{ cm}^2$ on a screen, with a viewing distance of 135 cm. The images presented to the two eyes were displayed side by side on the monitor and fused using a minor stereoscope mounted on a chin rest. A fixation mark (a centre cross) was used to aid the fusion of the two images and was located in the middle of each image. In Costello et al.'s paradigm (2009), they employed a frame for both images to help the convergence of the two images. However, we excluded the use of the frame because Chinese characters are dense and to employ a frame would potentially cause a visual competition between the frame and the stimuli. Characters appeared as light grey on a black background and subtended approximately 1 degree of visual angle. The use of a black background was to prevent participants from seeing the inner structure of the stereoscope. Characters were grouped by its character complexity and character frequency and the presentation order was chosen randomly on

each trial. Characters were presented to the left-eye or right-eye for each participant and the condition assigned to each participant was counterbalanced so that each target stimulus could be viewed in the left-eye or right-eye condition. All odd-numbered trials had the visual stimuli at the left and the high contrast noise mask at the right and for the even-numbered trials, vice versa. Thus, all participants were in both visual field conditions. The final data were also separated by the left-eye condition and the right-eye condition for further examination.

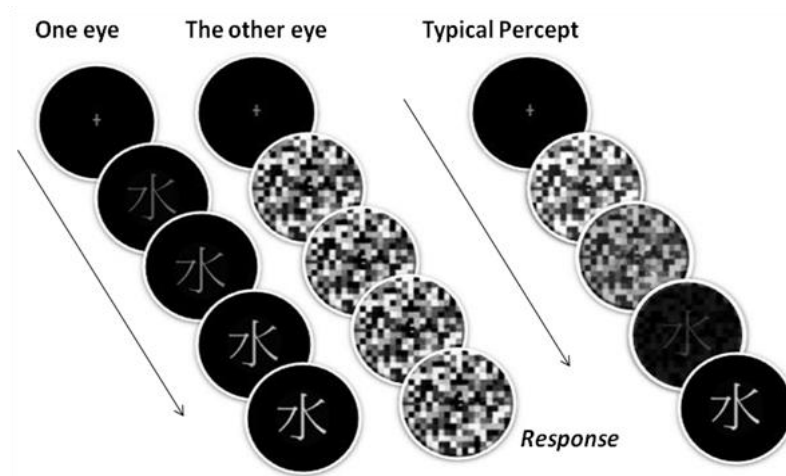


Figure 7: an example of the experimental paradigm. The target stimuli were grey Chinese characters and the noise masks were grey and white Mondrians. They were presented dichoptically. The right column is the schematic representation of the percept seen by the participants. The contrast of the characters gradually increased until reached to 70% contrast and the Mondrians were always presented with 70 % contrast. The sequence of presentation continued until the participants clicked the mouse to indicate detection of the character. Once the participants clicked the mouse, the stimuli disappeared.

3.1.4 Experimental procedure

The participants were first given an informed consent before the experimental session and were instructed specifically they can ask for a break during the experiment. Participants then were asked to sit in front of the haploscope and mount on a chinrest. The task was to click the mouse as an indication of the detection of the stimuli and to report which character they saw. The participants were instructed specifically that they need to respond as soon as they perceive the stimuli. Before the formal trials, participants were given 20 practice trials to familiarize the experimental paradigm (none of the characters used here were repeated with the formal trials). At

the beginning of each trial a fixation cross was first presented, in the centre of image, to stabilize fixation and to help with the fusion of the two images that was shown to each separately by a mirror haploscope. Participants were asked explicitly whether they could clearly see the fixation cross in order to ensure the fusion occurred normally and they were fixating on the right position. When the participants were ready, they clicked the mouse to initiate the first trial. After the participant clicked the mouse, a visual stimulus (a Chinese character) was presented to one eye and a dynamic high-contrast noise mask (with black and grey color as stimuli moving back and forth along the horizontal and vertical directions) was presented to the other eye simultaneously. The contrast of the target stimuli was ramped up gradually from 0% to 70% within a period of 1 s starting from the beginning of the trial and then remained constant until the participant clicked the mouse to indicate the detection of target stimuli. The contrast of the dynamic noise mask began at 70% in each trial. Instead of setting the contrast to 100% to induce greater suppression effect, the brightness of the stimuli and the dynamic noise mask were set at 70% to reduce participants' discomfort and fatigue and to lessen the illumination of the inside of the tube.

Between each trial, there was a one second interval to prevent the participant from double clicking the mouse as well as to prevent presenting characters in quick successions. There is an unavoidable potential for adaptation effects in this experimental paradigm (c.f., Harvey & Braddick, 2007). For each trial, characters would disappear as soon as the participants clicked the mouse and then the participants were asked to name the character they saw. The duration of the time from the beginning of each trial to the time the character was detected by the participants was recorded. The accuracy of the naming task was also registered. After the experiment was completed, participants were given 3 pounds as appreciation of the participation in this dissertation. The whole experimental session, including the practice session, lasted approximately 20 minutes (see Figure 7).

3.2 Results

The durations of how long it took for different types of Chinese characters (character complexity: simple/ complex characters, and character frequency: high frequency/ low frequency characters) to break out of inter-ocular suppression are compared. Response time of less than 0.87 s and error trials (participants clicked the mouse accidentally, before the target stimuli appeared) were excluded from further analysis. Results for correct RTs of different character types are shown in Figure 8. A pair *t*-test was used to compare the suppression time for characters with

different rates of complexity and frequency. There was no main effect for character frequency variable [$t(19)=-1.65$, $p>0.05$; $M= 2.208$ sec. for simple characters and $M=2.240$ sec. for complex characters], and there was no main effect for character complexity variable [$t(19)=-1.642$, $p>0.05$; $M= 2.230$ sec. for high frequency characters and $M=2.481$ sec. for low frequency characters]. However, although no significance, the average suppression time showed a trend that the complex words were detected slower than simple words (2.240 sec. vs. 2.208 sec., respectively) and it took low frequency words a longer time than high frequency words to gain dominance against the suppression noise (2.481 sec. vs. 2.230 sec., respectively). Overall, the average suppression time showed a trend that it took male participants a longer time than female participants to detect characters (2.534 sec. vs. 2.062 sec., respectively; see Figure 9). However, the difference was not statistically significant and there was no significant interaction between sex and character types [$p>0.05$].

An independent t -test was used to compare suppression time for naming accuracy. A main effect was obtained for character accuracy. Characters that were named inaccurately were detected slower than characters that were named accurately [$t(1589) = -10.315$, $p<0.0001$; $M=2.190$ sec. for accurate characters; $M=3.788$ sec. for inaccurate characters; see Figure 10]. Additionally, the accuracy data has shown a trend that low frequency characters led to low accuracy (among 1591 trials, 108 trials were named inaccurately and 84 of them were low frequency characters).

Right eye versus left eye

Furthermore, we separated the data of the right-eye condition and of the left-eye condition (target stimuli were shown to the right eye vs. target stimuli were shown to the left eye) for a further analysis. A paired sample t -test was used to compare whether there were any differences between the right eye and the left eye. In the condition of the stimuli being presented to the right eye, there was no main effect in character complexity variable [$t(19) = 0.358$, $p>0.05$] and character frequency variable [$t(19) = -0.608$, $p>0.05$]. However, a main effect in character frequency was obtained in the condition of the stimuli being presented to the left eye [$t(19) = -2.347$, $p=0.03$; see Figure 11]. When stimuli were presented to the left eye, it took the participants a longer time to detect low frequency characters than high frequency characters (2.468 sec. vs. 2.054 sec., respectively). Yet, there was no main effect in character complexity in the left eye condition [$t(19) = -0.551$, $p>0.05$]. Additionally, an independent sample t -test with variables of character complexity and character frequency was conducted to examine whether there were any

interaction between males and females among the suppression time between characters types with either eye. There was no significant interaction between character types, sex and either eye [$p>0.05$].

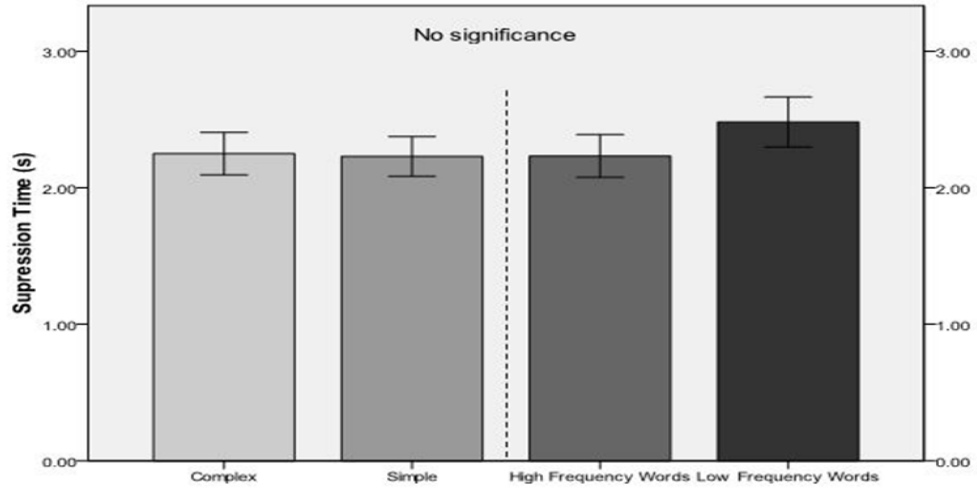


Figure 8. The average suppression time of different types of Chinese characters

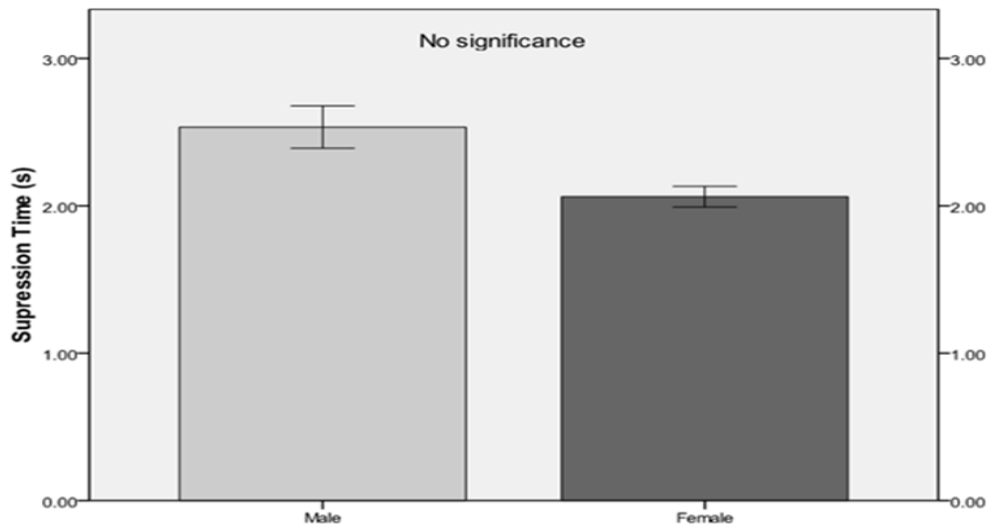


Figure 9. The average suppression time of male and female participants

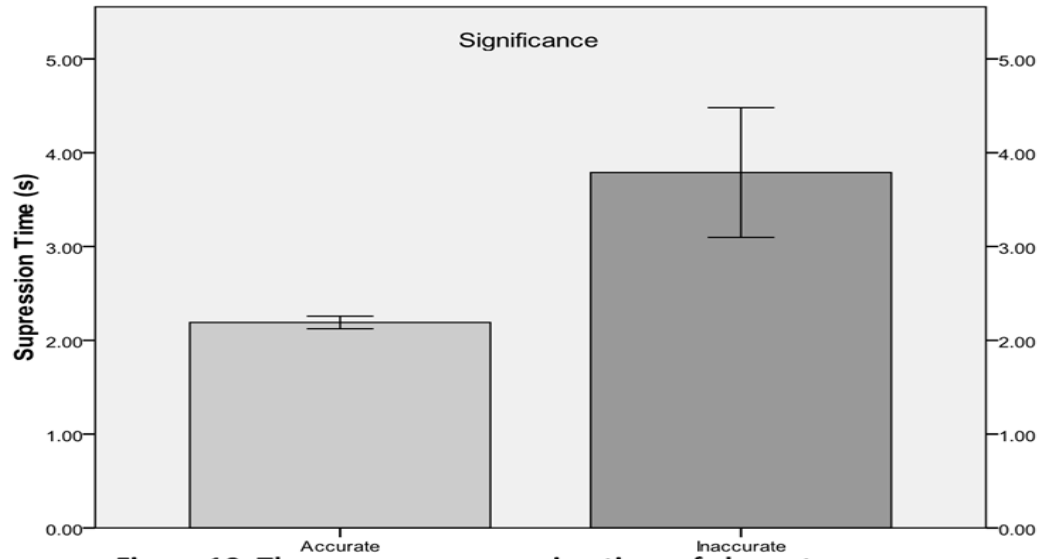


Figure 10. The average suppression time of characters were named accurately and inaccurately in the naming task.

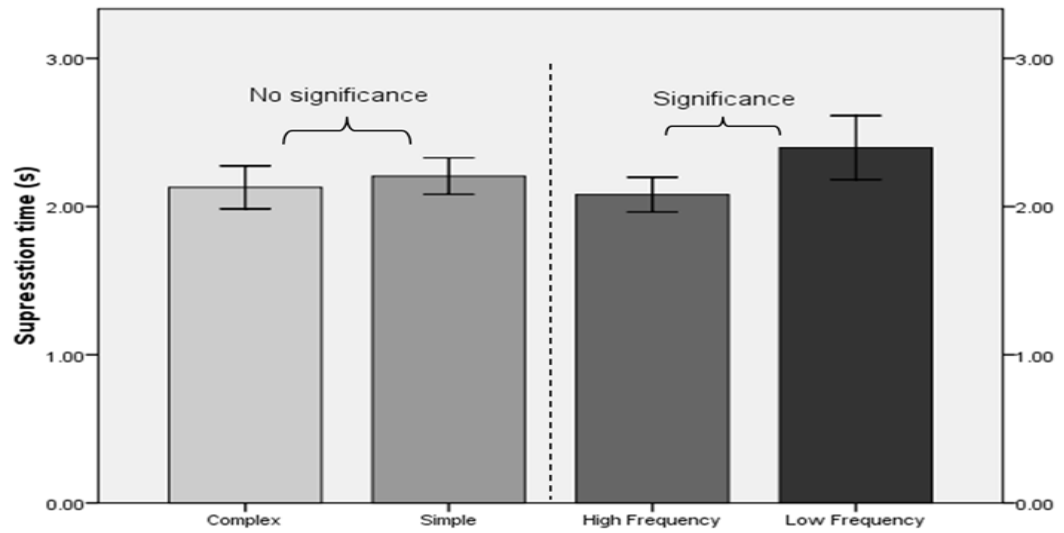


Figure 11. The average suppression time of different types of Chinese characters in condition when the stimuli being presented to the left eye.

3.3 Discussion

The results of this experiment showed no difference in the suppression time of different types of Chinese characters across the right and left eye condition (counterbalanced data). This indicates that, overall, the lexical properties and character complexity do not influence the inter-ocular suppression time. Nevertheless, the average suppression time across different types of Chinese characters demonstrated a non-significant tendency that it took high complexity characters a longer time than low complexity characters to be released from the suppression and high frequency characters were detected faster than low frequency characters.

Interestingly, the frequency effect was obtained when the target visual stimuli were being presented to the left eye. The results indicate that when the target visual stimuli were being presented to the left eye, the lexical properties of Chinese characters had an influence on the inter-ocular suppression time; low frequency words were detected slower than high frequency words. It is unclear why the frequency effect was only found when the stimuli being presented to the left eye. An eye dominance effect may contribute to the finding. Most people are tested as right eye dominant. Thus, it may be possible that when the target stimuli being presented to the left eye, the stimuli were suppressed at first since the left eye is the sub-dominant eye for most people. Consequently, the suppression time was prolonged in which potentially enhanced the effect size of the frequency effect.

Furthermore, the processing difference in visual pathways may potentially contribute to the frequency effect in the left eye. Previous studies have suggested that contralateral pathways (e.g., left eye to right hemisphere) are better at projecting information than ipsilateral pathways (e.g., left eye to left hemisphere). Although most studies addressed these visual pathway differences with binocular stimulation, Tossy, Werring, Plant, Bullmore, Miller and Thompson (2001) reported that monocular stimulation of either eye could give a similar anatomical distribution of visual cortex activation. In other words, a monocular stimulus would also induce a similar pattern of cerebral activation, at least between normal subjects. In Tossy et al.'s study, they found that the contralateral hemisphere was activated more strongly than the ipsilateral hemisphere when either eye was stimulated. Tossy et al. concluded that contralateral projection is more efficient than ipsilateral projection in each eye. As a result, a possible explanation of the frequency effect obtained in our experiment may be that in the left eye the visual information would first be projecting to the right hemisphere of the brain (benefit by a contralateral projection) where the

remote semantic associates are activated. Chinese low frequency characters are often contained greater ambiguity than high frequency characters (Huang, Lee, Tsai, & Tzeng, 2011). Thus, to resolve the lexical ambiguity is important in the processing of word recognition. There are studies suggested that the subdominant word meaning may be built in the right hemisphere (Burgees & Simpson, 1988). Accordingly, when the characters were projecting to the right hemisphere, the subdominant word meanings were available for retrievals. It could be that the right hemisphere is playing a crucial part in the resolution of lexical ambiguity. The frequency effect in the left eye was therefore obtained. In sum, although speculatively, this processing difference between visual pathways and cerebral hemispheres could be a plausible explanation that why the frequency effect was only found in the condition when the characters were presented to the left eye and the noise mask were presented to the right eye.

The result may also indicates that the locus of rivalry processing could lie at a higher cognitive level such as visual word recognition, instead of a low level processing. Hence, the frequency effect we found in the left eye suggests that meaning of the characters could be accessed even when the characters were suppressed by the high contrast noise mask. The results in the overall accuracy data also suggest this possibility. The result of the accuracy data showed the average suppression time of characters that were named inaccurately by participants was significantly longer than the average suppression time of characters that were named accurately. Nevertheless, our finding does not contradict that binocular rivalry may involve processing at multiple levels (multistage competition; see Freeman, 2005; Nguyen, Freeman, & Alais, 2003) but to suggest the possibility that the extraction of symbolic meaning could occur even under inter-ocular suppression.

Additionally, although previous findings have shown the gender difference that the male brain tend to be more distinctively lateralised in favor of the left hemisphere for phonological processing than the female brain (Hsiao & Shillcock, 2005). However, in this current study, no significant gender difference was found in all conditions.

4. General discussion

The finding of this dissertation demonstrated that, in the reading of Chinese characters, the inter-ocular suppression was not affected by character complexity and character frequency in an overall condition (stimuli being presented to the right or the left eye). There were no significant interactions between character types and sex neither. However, interestingly, in the condition

when the characters were presented to the left eye, a strong lateralised effect may have shown; a frequency effect was only found in the condition when the Chinese characters were presented to the left eye. The results demonstrated that, when the characters being presented to the left eye, it took participants a longer time to perceive low frequency characters than high frequency characters during inter-ocular suppression. In other words, the recognisability of the characters possesses an advantage in breaking the inter-ocular suppression in the left eye. The finding suggests that the contralateral projection may be more effective than ipsilateral projection since the result potentially reflected that the right hemisphere may be playing a special role in processing the lexical ambiguity.

First of all, with respect to the recognisability of the characters, this frequency effect we found in the left-eye condition is consistent with previous studies which demonstrated that objects with high familiarity and recognisability have an advantage of predominance during binocular rivalry (Yang, Zald, & Blake, 2007; Jiang, Costello, & He, 2007). However, previous studies were using either meaningful images versus meaningless images (upright faces vs. inverted faces) or a native language versus a foreign language (Chinese vs. Hebrew) as stimuli and to measure which type of stimuli breaking suppression from the high-contrast noise mask faster. One major difference between their studies and this current study is that we only employed Chinese characters as target stimuli instead of measuring the competition of two different orthographies or images. Therefore, the competition in this current study is only between the high contrast noise mask and the semantic and structural properties of the Chinese characters.

Theoretically, to access the lexical properties requires the activation of fine semantic associates in the left hemisphere. Thus, the involvement of fine semantic coding is necessary in order to complete the word recognition. In the condition when the stimuli being presented to the left eye, the visual information may be sending to the right hemisphere more efficiently (benefit by a contralateral projection). In order to gain access to phonological information, extra loading would be needed for the information being sending to the left hemisphere where the phonological information could be activated. This additional computing loading might potentially contribute to the frequency effect in the left eye due to the style of processing and the difference in cerebral loading that enhance the response suppression of the stimuli when the stimuli are symbolic carriers (i.e., Chinese characters) rather than images.

Additionally, previous studies have demonstrated that for Chinese readers there are more Stroop interferences when the colour words were presented to the left visual field (Tsao, Wu, &

Feustel, 1981). The result was commonly used as evidence that different functional lateralisation was adapted by the characteristic of the orthography, thus to imply that the right hemisphere is engaged more than the left hemisphere when reading single Chinese character words. However, the result could also be used to argue that colour is rather a concept that is linked with a large number of remote associates that is more connected to the right hemisphere (see Dimond & Beaumont, 1972, for a detailed analysis). In the Chinese characters Stroop tasks, the task involved not only to identify the character (colour-name association) but also involved to categorize their mental representations of colour (colour categorization and colour-object association; see De-Renzi, 2000). In other words, besides the word recognition, the participants were required to make a connection between the object (ink) and which colour category it belongs. Current theories has shown that semantics associates or perceptual representation are activated through the coarse coding in the right hemisphere. Thus, when the words were presented to the left visual field, the perceptual prosperities (the colour) may be decoded readily by the right hemisphere, therefore it might enhance the interference effect at later stage of visual information processing when the observers need to access the semantic codes (colour name). Thus, the interference effect may reflect more in the respect of the prolonged response time (production) than in the respect of the prolonged detection time (perception). It could explain why for Chinese readers the interference effect is greater when the stimuli were presented to the left visual field and potentially to support the possible interactions between hemispheric difference and inter-hemispheric pathways.

Yet, when Tsao, Wu and Feustel (1981) compared the result with their previous findings (1979; same mythology but to English readers), they found that overall Chinese readers experienced more Stroop interferences than English readers and when the colour words were presented to the left visual field, the Stroop interference effect is also stronger for Chinese readers than English readers. Indeed, this difference across the two languages could not be easier explained by the interaction of inter-hemispheric pathways and different hemispheric processing style. It is suggested that such difference might be due to a possible LVF-RH advantage in processing Chinese characters (a logographic script), thus for Chinese readers, colour information and colour words might be completing under the same perceptual capacity in the right hemisphere (Davidoff, 1976; Pennal, 1977; Tsao, Wu, & Feustel, 1981). On the other hand, the competition might be less for English readers.

The spatial layout and the pictographic orthographic feature of Chinese is the reason why researchers speculate the possibility of a heavier involvement of right hemisphere in processing Chinese characters. However, in Chinese word recognition, past studies have shown inconsistent results. When some studies showed a left visual field (LVF-RH) advantage in reading single Chinese characters (pictographs), some studies found no evidence in right hemisphere dominance. These inconsistent results in Chinese word recognition may be due to the visual complexity of the orthography and its complex rules of construction. On the other hand, it is well demonstrated that, in English word recognition, there is a right visual field (RVF-LH) superiority. According to the dual route model in visual word recognition, there are two routes to access our mental lexicon. One is the phonologic route and the other one is the direct route. The phonologic route is mapping letters (or characters) through phoneme to appropriate lexical entries, when the direct route is mapping directly from letters (or characters) to its meaning.

It is commonly accepted that alphabetic languages (e.g., English) rely more on the phonologic route. As for logographic languages (e.g., Chinese), some believe that it may be more rely on the direct route. Indeed, the visual representation of Chinese orthography is more close to iconic representation. In reading Chinese characters, the identification of the visual feature is essential. The high complexity of Chinese orthography allows Chinese characters to contain richer linguistic information (both semantic and phonetic information) than most, if not all, alphabetic languages. The identification process would include the identification of different radicals (components). Naturally, given that the semantic radicals would indicate some aspects of the semantics, the mediation of phonological information might not be as important as in alphabetic languages. However, it should also be noted that purely pictographic characters are only about 1% or 2% of modern Chinese characters. 90% of modern Chinese characters are phonetic-semantic compound characters (DeFrancis, 1989). Previous research has demonstrated that the pronunciation of the characters is activated despite the readers were only asked to evaluate the meaning of the character (Prefetti & Zhang, 1995). Overall, there are still much need to be resolved on this issue (see Prefetti, 2003, for a comprehensive profile of the universal principles of reading).

Our finding is not in contrast with the possibility that to some extent, in the respect of reading, Chinese may be more a RH language than alphabetic language but to suggest that when the visual information was projected to the right hemisphere where the semantic remotes associates and the subdominant word meaning are available for retrievals, the character frequency

and the lexical ambiguity may could affect the duration of inter-ocular suppression. Furthermore, since the visual information being projected to the left eye would be sent to the right hemisphere more efficiently (by contralateral pathways: left eye to the right hemisphere), the additional computing loading for the visual information to be forwarded to left hemisphere to achieve phonological information may contribute to the frequency effect we found in the left eye as well. In addition, our finding also in line to suggest the possibility that binocular rivalry involves high-level processing.

5. Conclusion

In this dissertation, we have investigated whether the type of Chinese characters influence the duration of inter-ocular suppression. We have found that, (i) overall, the inter-ocular suppression time did not differ significantly across different types of Chinese characters, (ii) the frequency effect was obtained in the left eye which suggests that the contralateral projection is more efficient than ipsilateral projection and the lateralized effect could extend to the phrase of rivalry suppression, (iii) the lexical ambiguity of characters could had an effect on binocular rivalry when its representation was enhanced by lateralized effect, (iv) rivalry processing might be lie at a high level in visual pathways.

These results provide several potential implications for future research. First of all, although the character complexity did not show any significant influence on inter-ocular suppression time, the descriptive statistics have shown a range of suppression time from 21s to 0.87s among the group of characters with high and low complexity. If it is not the complexity of the characters to drive this difference, what might be accountable for the difference in the suppression time? A number of following up experiments could be carried out to resolve this mystery. For example, research has shown that the cognition of Chinese characters could be influenced by learning experience (Yeh, Li, Takeuchi, Suh, & Liu, 2003), therefore further investigations could be to compare the suppression time between people with different levels of reading skills or between native Chinese speakers and non-native speakers. Another possible factor could be that: if it is not the strokes number that might influence the inter-ocular suppression, could the character regularity and consistency be factors? Future experiments with more controlled stimuli might could lead us in a more correct direction to the answer.

Furthermore, it might be interesting to examine the loading of cerebral hemispheres by using phonetic compounds to observe the size of the Stroop effect. There are a number of colour words

in Chinese that are phonetic compounds (e.g., 紅 and 靛). Thus, what might be the implication if we present the colour word to the right visual field when the phonological information of the phonetic radical could be projected to the left hemisphere where the information could be decoded readily? Will the Stroop effect enhance or lessen? Will the extent of the effect be different if the stimuli are presented to the left visual field?

Lastly, there are currently only a handful of research that used CFS paradigm to examine the semantic processing (Costello, Jiang, Baartman, McGlennen, & He, 2009 ; Yang & Yeh, 2011). It is no surprise given the CFS paradigm is a recent technique. Recent research employed with the CFS paradigm to examine the implicit processing of semantics have demonstrated promising results (e.g., priming). It has shown that the CFS paradigm is a good tool to examine the influence of structural and lexical properties of language. To conclude, the combination of the CFS paradigm and Chinese orthography has great potential to improve our understanding of the cognitive processing underlying reading of Chinese characters and how the cerebral hemispheres interact with binocular and monocular vision. Future research with more controlled conditions could help to resolve fruitful issues in this area. Moreover, in a broader sense, to provide better understanding of the processing of language and to identify cognitive constraints on different languages would in return shed light on how language evolves to the way it is and why we process language as we do.

6. References

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Appendix A: Ccharacter List

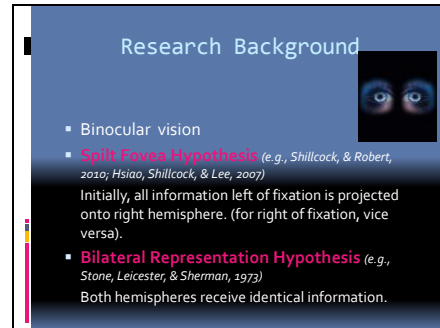
Practice section: character list			
High Frequency characters	Low Frequency characters	Complex characters	Simple characters
安	磬	獲	白
請	厓	邀	金
美	薊	繼	木
神	譽	獵	山
是	觥	馨	下
Experimental section: character List			
High frequency characters	Low frequency characters	Complex characters	Simple characters
愛	鞍	變	大
茶	莽	簿	刀
吃	躋	擊	方
電	酌	覺	光
國	竇	警	火
好	犢	黎	木
花	鶴	鏟	女
風	粼	靈	人
看	覷	齡	日
買	羶	龍	上
米	噬	爐	手
男	蟀	壽	水
書	夙	樹	天
我	癩	題	田
想	紬	嚇	土
笑	虞	蕭	文
信	胤	興	小
衣	藻	藝	心
早	塚	櫻	中
走	鑫	雜	子

Appendix B: slides of a job talk in the University of Dundee (MS.C Project).

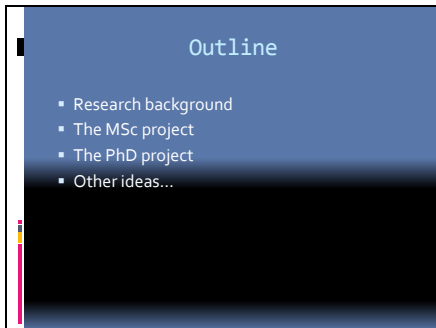
1



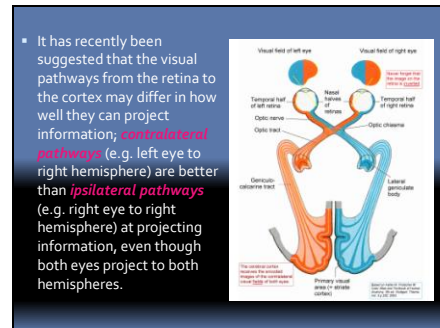
4



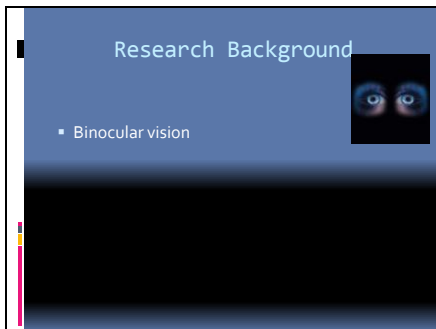
2



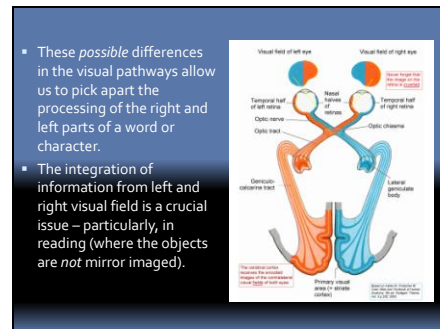
5



3



6



7

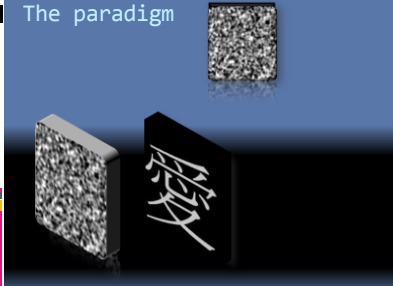
MSc Project:
Inter-ocular facilitation and suppression in the reading of Chinese characters

- How is binocular vision achieved in reading Chinese characters?
- Chinese characters:
 - dense
 - logographic
 - different radicals (components)



10

The paradigm



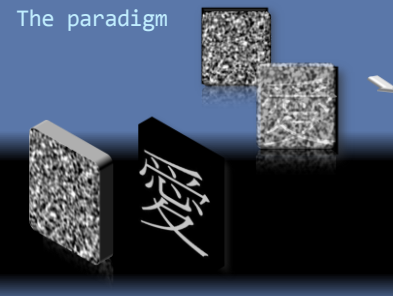
8

MSc Project:
Inter-ocular facilitation and suppression in the reading of Chinese characters

- Subjects: Native Chinese Readers
- Stimuli: Chinese characters
- Design:
 - Subject gender (between-subjects): Male / Female
 - Character complexity (within-subjects): Complex/ Simple words
 - Character frequency (within-subjects): High Frequency (common) / Low Frequency (rare) words
- Task: Naming

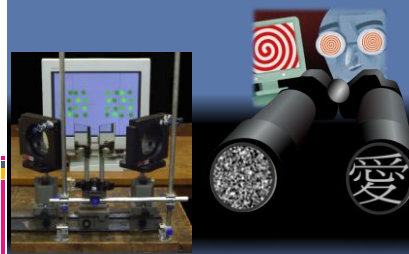
11

The paradigm



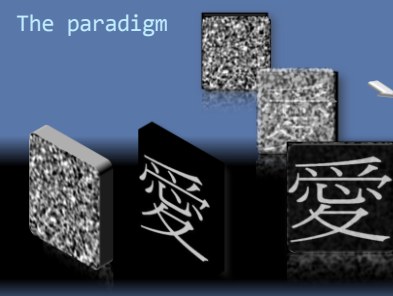
9

The paradigm



12

The paradigm



13

Results

Reaction Times

- Frequency effect : HF < LF
- Gender effect: Female(1.5 s) < Male (2 s)
- No complexity effect

16

Critical issues:

I. **The bilateral / mono-lateral issue**

14

Conclusions

- The integration and suppression processes between the two visual fields are affected by character frequency and reader's gender.
- However not by character complexity.
- Thus, simple visual complexity does not affect the binocular vision in Chinese word recognition, but lexical properties (e.g., frequency) do.

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Critical issues:

I. **The bilateral / mono-lateral issue**

- Could the position of the two different components affect attentional shifts on them?
- If so, in what time-course?

15

Present Project: Chinese characters reading

^{LF} 櫻	^{RF} 鸚	^{LF} 花	^{RF} 貨
Cherry Tree	Parrot	Flowers	Commodity
櫻	鸚	花	貨
Tree	yīng Bird	Of planet	化 huā
		貝	Valuable objects

18

Critical issues:

II. **The task effect**

19

Critical issues:

II. **The task effect**

- Could the attentional shifts and their time-course be modulated by the task demand?
- e.g., Phonetic (P) component might receive more attention in a phonological task, whereas semantic (S) component might attract more attention in a semantic task.

Semantic Task Phonological Task

22

Eye-tracking

- Useful for investigating
- **Spatial** aspects of attention shifts within characters

S P P S S P P S

櫻 鸚 花 貨

20

Critical issues:

III. **phonological mediation in word recognition**

23

Eye-tracking

- Useful for investigating
- **Time-course** of attention shifts on different information cues within characters
- early measure (*first fixation time*) vs. late measure (*total reading time*)?
- scan path?

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Critical issues:

III. **phonological mediation in word recognition**

- Is it necessary in processing Chinese characters?
- e.g., How much attention do readers pay on P component?
- Or would it depend on the position of P and S components, and/or on the task demand?

鸚

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The Goal!

- My goal will be to identify separate component processes in character recognition, specific to different types of information in Chinese characters.
- That will help us understand what aspects are (and are not) universal across typologically different languages.
- Hence, it will help us understand how and why we read and understand language in general.