Hemispheric Lateralisation in the Recognition of Chinese Characters

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Declaration

I declare that this thesis was composed by myself; the work contained therein is my own, except where explicitly stated otherwise in the text; and that the work has not been submitted for any other degree or professional qualification except as specified.

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Abstract

The object of this thesis is to investigate hemispheric lateralisation in the processing of Chinese character recognition. I used single Chinese characters and multiple character words as experimental stimuli, aiming to examine hemispheric lateralisation phenomena and related findings in Chinese, a so-called ideographic script, that have been explored in alphabetic languages, such as English. The body of studies in this thesis was based on three themes in the following order.

I started with unilateral presentation and the word-length effect in the recognition of Chinese multiple-character words (Experiment 1), and found that Chinese did not show significant hemispheric lateralisation of the processing of these words. However, the Chinese stimuli did show a non-significantly skewed information contour in two-character words and a significantly skewed information contour in four-character words in a corpus analysis (Experiment 2). This fact indicates that hemispheric lateralisation should have been expected in processing Chinese words, allowing the asymmetric information contour to be equally split and projected to the two hemispheres, in line with one theory of the processing of alphabetic orthographies. I argue that any lateralisation might have been eliminated by the high complexity and density of Chinese words and single characters, by the rightward skewing of information within Chinese characters, and by insufficient experience of horizontal, as opposed to vertical, Chinese text. However, I argue that there is a potential role for the information structure of words, on the basis of a demonstration (Experiment 3) that the information structure of English words may assert itself in a RVF lateralisation found for English words in Chinese speakers with English as a second language, there being no clear hemispheric lateralisation for Chinese orthography.

Secondly I investigated the Bilateral effect in the recognition of Chinese multi-character words (Experiment 4), and found overall no significant bilateral advantage, but a tendency towards such an advantage with increase in word-length, resembling other claims in the literature. Any increasing bilateral advantage was attributed to (a) the complexity of Chinese words, (b) a Gestalt effect in perception, (c) redundancy gain, and (d) foveal splitting and information in parafoveal vision. I further explored the Bilateral effect using first an overlapped presentation (Experiment 5) which uniquely allowed different versions of the same word to be presented at different spatial scales about the same fixation point. This novel technique revealed no redundancy effect in these conditions, suggesting either a dissociation of the parallel processing at the two spatial scales, or no summation of activation for this presentation paradigm. I further explored the parameters of the

Bilateral effect as a redundancy effect by expanding the number of stimuli and using a "Pop-Out" paradigm to encourage early preattentional location of the target and to provide a more closely understood version of the redundancy effect (Experiment 6). This experiment produced a significant redundancy effect, in that the other versions of the target in the background facilitated target processing. I compare this significant redundancy effect with multiple non-target characters with the overall non-significant Bilateral effect from Experiment 4, and attribute the difference to redundant background information being simultaneously available to both hemispheres in Experiment 6, but only to one hemisphere in Experiment 4, in line with the split-fovea model that I discuss.

Finally, I focused on Chinese single characters by developing a new methodology taken from face recognition research, specifically the Thatcher illusion, concerning the loss of configural processing (Experiments 7-1, 7-2 and 7-3). I demonstrate that the recognition of Chinese single characters involves both broad and fine configural spatial processing, and I show how this line of research might be used to tease apart processing differences involving the different radicals.

In sum, I conclude that the combined issues of spatial and informational complexity are deeply implicated in Chinese character recognition from the most basic to the most complex units: strokes, radicals (stroke patterns), single characters, and multi-character words. These factors are potent influences on the ways in which processing might be distributed between the hemispheres in the reading of Chinese, and they reduce the pattern of LH lateralisation found in alphabetic languages, but they impart a more varied and labile pattern of lateralisations that may be studied in part using the novel techniques, and novel variants of existing techniques, that I have developed in this thesis.

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Chapter 1. Introduction

The object of this thesis is to investigate information processing in the brain, with respect to Chinese characters. We will use single Chinese characters and multiple character words as experimental stimuli to test hemispheric lateralisation phenomena. This thesis re-examines the findings established in English and extends the analysis to Chinese. The essential motivation in carrying out these studies has been to examine how hemispheric lateralisation – as it has been explored in the processing of English words – might work in an ideographic and highly complex language such as Chinese, with the information profile of the characters/words and the lexicon interacting with the processing preferences of the two hemispheres of the brain.

According to the literature on Chinese reading, Chinese and English are distinct at least in three aspects. First, at the single character level, Chinese characters contain denser information than English words, because a large proportion of single Chinese characters comprise a single semantic radical and a single phonetic radical, which represent the meaning of a character and a hint about the pronunciation of the character, respectively. Hence, the processing of Chinese characters goes through a complex pathway which inevitably interacts with semantics and phonology, whilst the reading of English words can go directly from orthography to its phonology. Secondly, from the perspective of Chinese words, word segmentation within Chinese sentences is a research topic, because Chinese does not have clear word boundaries. When Chinese words are written in sentences, the inter-character space and inter-word space are identical. Thus it is not straightforward to segment one word from the next, nevertheless the segmentation and parsing of words has to be done, whether one prior to the other or simultaneously, in order to process the sentence. The last, but not the least difference, is at the sentence level: Chinese script can be written in several different directions. The orientation of Chinese sentences can be horizontal from left to right or vertical from top to bottom with the first line being started from the right and the next line to the left. In fact, there is a third orientation which is not as commonly used as the other two: Chinese sentences may be written vertically from top to bottom with the first line being started from the left and the next line to the right.

The spatial features of Chinese must play an important role in the issue of word/character recognition. This thesis aims to investigate this issue specifically from the perspective of hemispheric division and hemispheric lateralisation, with a series of studies.

The body of studies in this thesis was based on three themes in the following order. We started with unilateral presentation and hemispheric asymmetry and the word-length effect in the recognition of Chinese multiple-character words. Secondly, we investigated the Bilateral advantage in Chinese word recognition with expanded research on multiple numbers of characters in both an overlapped presentation and a "Pop-Out" paradigm. Finally, we focused on single Chinese characters to explore right-hemisphere (RH) dominant holistic processing versus the left-hemisphere (LH) dominant componential processing hypotheses of Chinese character processing. All these three themes share the common feature of the information profile of the orthography interacting with the divided processing of the brain.

The layout of this introductory chapter starts from Section 1.1: an introduction to Chinese orthography and its characteristics in relation to this thesis. Section 1.2: normal Chinese reading without manipulation of visual fields: the procedure of learning to read Chinese, and relevant research in the field of Chinese reading, including the word superiority effect and relevant aspects of language processing with regard to orthography, phonology, semantics, morphology and syntax. Section 1.3: models and issues in the processing of Chinese. Section 1.4: issues concerning hemispheric lateralisation and all aspects of lateralised language processing, from early behavioural data to the most recent clinical research, to provide a framework of what has been done and what is currently known about the processing of Chinese script. Section 1.5: the motivation of the three themes in the thesis. Section 1.6: central questions, and the main proposition being investigated in the thesis.

1.1. Introduction to Chinese writing

Chinese spoken language has eight main streams of dialect; the most well-known is Mandarin, the "official language" of Mainland China. Chinese orthographies were united centuries ago, but nowadays there are two kinds of orthography in use. The "traditional font" is used in Taiwan and Hong-Kong, and the "simplified font" is used in Mainland China and Singapore. The research in this thesis was based on traditional fonts of Chinese.

1.1.1. The basic units of Chinese words

There are four levels of orthographic units at which Chinese words can be described: strokes, radicals, characters and then the word, whilst the basic semantic unit is the morpheme.

Stroke and radical level

First of all, strokes are as simple as "丶", "一", "丿", "乛", "乚" and "亅"; there are 24 kinds in total. The segmentation of strokes is not always directly visible. For example, a radical 冖 might be counted as three strokes, but it is made of only two stokes: "丶" and "乛". Likewise, the character "力" is comprised of 2 strokes, "天" of 4 strokes and "其" of 8 strokes. The average word length in English is 5-6 letters, whereas the average number of strokes in Chinese characters is about 6 (Wang, Inhoff, & Chen, 1999). The number of strokes in a character may vary from 1 to 32 (Fang, 1994); though the average

一畫		一	丨	丶	丿	乙	亅	二畫		二	亠	人	儿	入	八	冂	冖
冫	几	凵	刀	力	勹	匕	匚	匸	十	卜	卩	厂	厶	又	三畫		口
囗	土	士	夂	夊	夕	大	女	子	宀	寸	小	尢	尸	屮	山	巛	工
己	巾	干	幺	广	廴	廾	弋	弓	彐	彡	彳	四畫		心	戈	戶	手
支	攴	文	斗	斤	方	无	日	曰	月	木	欠	止	歹	殳	毋	比	毛
氏	气	水	火	爪	父	爻	爿	片	牙	牛	犬	五畫		玄	玉	瓜	瓦
甘	生	用	田	疋	疒	癶	白	皮	皿	目	矛	矢	石	示	禸	禾	穴
立	六畫		竹	米	糸	缶	网	羊	羽	老	而	耒	耳	聿	肉	臣	自
至	臼	舌	舛	舟	艮	色	艸	虍	虫	血	行	衣	襾	七畫		見	角
言	谷	豆	豕	豸	貝	赤	走	足	身	車	辛	辰	辵	邑	酉	釆	里
八畫		金	長	門	阜	隶	隹	雨	青	非	九畫		面	革	韋	韭	音
頁	風	飛	食	首	香	十畫		馬	骨	高	髟	鬥	鬯	鬲	鬼	十一畫	
魚	鳥	鹵	鹿	麥	麻	十二畫		黃	黍	黑	黹	十三畫		黽	鼎	鼓	鼠
十四畫		鼻	齊	十五畫		齒	十六畫		龍	龜	十七畫		龠				

Figure 1. Chinese radicals.

number of strokes is about 6, the average of the most common characters was shown to be 12.3 in a study by Cheng and Chen (1991).

It was previously thought that strokes are a processing level analogous to English letters. However, it must be noted that there is no compositionality at this level. In English, the letters "a", "c" and "t" can combine to form the words "act" or "cat", with a lawful relationship between the order of the letters and the pronunciation of the word. In Chinese, there is no comparable compositionality, or systematicity, involving individual strokes and either pronunciation or meaning. As Chen, Allport and Marshall (1996) have suggested, the stroke pattern is more crucial than the number of strokes in word recognition. The stroke patterns to which they referred were patterns like 亻人冖冫冂刂刀匚广 忄心扌手 (see Figure 1). They are elements in a fixed set of recurring spatial designs, and so-called radicals. This observation affirms the fact that the stroke pattern (i.e. the identity of the radicals) is the level at which there is greatest systematicity and compositionality between orthography, phonology and semantics in Chinese characters. Thus the number of strokes a character contains has less psychological salience than the identity of the radicals it contains.

Radical level

Chinese people have categorized characters by the different types of radicals since 147 A. D., when Xu Shen attributed all characters to 540 radicals. In the Ming dynasty, the number of radicals was reduced to 214. The first dictionary using the 214-radical system was Mei Yingzu's *Zihui* (Character corpus) in 1615, containing more than 30,000 characters. This system is the one used today at least for characters in traditional fonts. The 214 radicals are listed in Figure 1. The same radical can be located in several positions in different characters. For example, the radical 刀 "knife" is written in the bottom of the character 券, or written as a "standing knife" 刂 in the right of the character 到. The radical 心 "heart" is normally written as the central stroke pattern of the character 愛, as a "standing heart" 忄 in the left of 情, or as four dots in the bottom of the character 恭. The radical 人 "man" is written as a "standing man" 亻 in the left of the character 仁, or it can be written in the bottom of 兒. The radical 手 "hand" is simplified to be three strokes and stands like 扌 on the left of the character 抱, or in the bottom of the character 擎.

The radicals we have introduced so far are called semantic radicals or lexical radicals, as they are the units used to classify the orthography of Chinese single characters in the dictionary. The advantage of classifying characters by orthography is that a reader does not have to know the pronunciation or meanings of the character when looking up characters in the dictionary, as long as one can recognize the semantic radical a character comprises and the number of the rest of the strokes in the character. For some characters there is no problem in finding the semantic radical, but for others it may be hard to judge which part of the character is the radical, because semantic radicals are the matrix part of a character. For example, the character for "sky" 天 can be

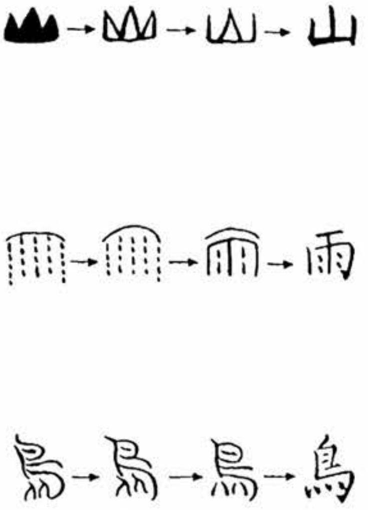


Figure 2. An example of the transformation of Chinese logographs. From top to bottom: 'mountain', 'rain' and 'bird' (reprinted from Hung & Tzeng, 1981).

classified possibly under the radical "great" 大 and under "one" 一, whilst the three-portion character 荆 (jing) seems to have a radical "grass" 艸 and the radical "knife" 刀. As for the character 匞 (jian4), the semantic radical is 匚 which is seen like a background to the central figure 工 (gong1).

Apart from the semantic radicals, there are the phonetic radicals which, together with semantic radicals, make up 80~85% of Chinese characters. Numerically these different radicals have been estimated at 214 and 1499 respectively (Perfetti & Tan 1999). Phonetic radicals are easily named as they have a consistent pronunciation of their own, and most of them are integrated characters when standing alone. These 80% of characters are called phonetic complex characters, as they always consist of a semantic radical signalling word meaning, and a phonetic radical providing a cue (of varying reliability) to the pronunciation of the character. The compositional strategies of characters are introduced in the following section.

Character level

Several systems have been used to classify Chinese orthography. The most common of all is an ancient system, which categorised Chinese characters into four types, pictographs, ideographs, semantic complexes and phonetic complexes, according to the ways they were composed.

Pictographs (象形字) are picture-like characters (see Figure 2), such as 雨 for "rain" and 鳥 for "bird". The leftmost pictures are the ancient ideographs; the rightmost ones represent the words that are used currently. This kind of character originated from pictures of concrete items, but the shapes of characters were changed through time.

Ideographs or logographics (指事字) are characters representing abstract meanings, such as 一 for "one", 二 for "two"; putting some strokes above a horizontal line, 上, represents "above" and some strokes below a horizontal line, 下, represents "under".

Semantic complexes (會意字) (also termed Logical aggregates or Semantic compound characters) are characters that are made of two or more semantic radicals and form a new meaning. The compositional strategies for making up a character are various. For example, 女 ('nu3', woman) and 子 ('tzu3, son) together form the character 好 ('hao3', good); the radical 羊 ('yang2', sheep) and the radical 大 ('da4', big) together make the character 美 ('mei3', beautiful); the radical 宀('ian3', roof) and the radical 女('nu3', woman) together form a character 安 ('an1', peace). The meanings of these characters are retrieved from both of their semantic radicals, and the radicals provide no hints for the pronunciation.

The fourth type of characters is termed Phonetic complexes (形聲字), which account for the largest percentage of Chinese characters. More than 80%

魷 崗

Figure 3. Examples of phonetic complexes.

of characters are made up of a phonetic component and a semantic radical, as shown in Figure 3. The character 魷, meaning "squid", is made up of a semantic radical 魚 in the left position, meaning "a kind of fish", and a phonetic radical 尤 in the right of the character, providing the pronunciation: – 魷 and 尤 are pronounced the same. Another character 崗 is made up of a semantic radical 山 (meaning "mountain") in the top position and a phonetic radical 岡 in the bottom position to provide the pronunciation.

The position of the semantic radicals is not specified, though semantic radicals tend to appear on the left side of phonetic compounds. However, this positional flexibility allows a phonetic component to appear in any position (left, right, top, bottom, or periphery) within a character (Feldman & Siok, 1997), though the majority are in the right hand side of a character. A phonetic complex character is not always pronounced as indicated by its phonetic radical. Only 38 percent of complex characters have the same pronunciation as their phonetic radicals (Zhu, 1988). In cases where there is no phonetic information, the veridical pronunciation must be obtained indirectly from the whole orthographic form, as opposed to more directly via the phonetic radical.

Integrated characters and complex characters

The first two of the four types of character are called integrated characters or 文 (wen2), as they are ideograph symbols and mostly consist of simple strokes or one radical (or inseparable radicals). Being distinct from integrated characters, the other two types of character are called complex (or compound) characters or 字 (zi4). Complex characters are characters formed by

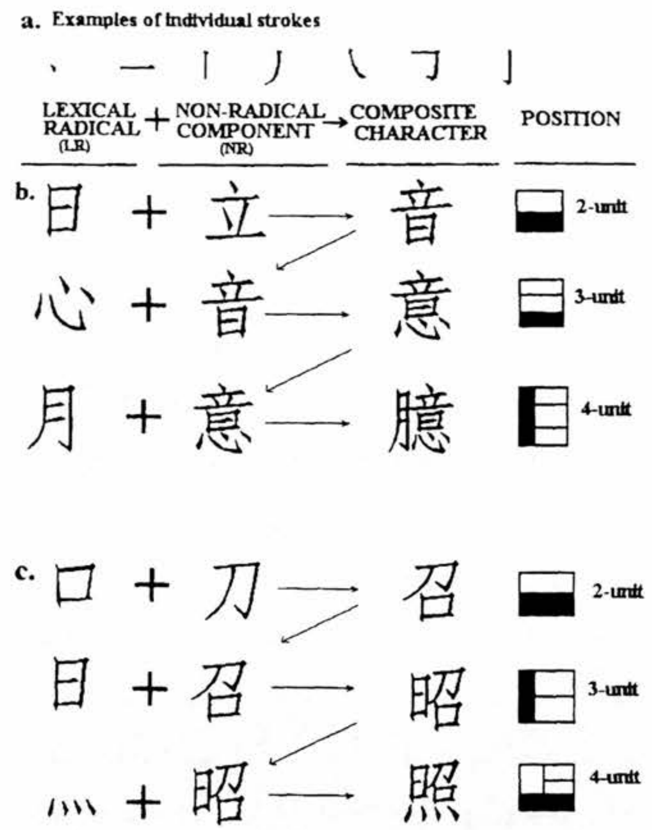


Figure 4. Composition of Chinese characters
(Chen, Allport, & Marshall, 1996).

combinations of simple characters. That is, Chinese orthography is constructed from a combination of radicals, and a combination of characters.

Examples of the composition of a character are demonstrated in Figure 4: a. shows the single strokes that can be used to compose radicals, while b and c show the way radicals form a complex 2-, 3- and 4-portion character. Two radicals, "立" at the top and "日" at the bottom, make the character "音"; three radicals "立", "日" and "心" make the character "意", and 4 units "立", "日", "心" and "月" make the character "臆". The dark areas in the right-most column present the regular position of the semantic radical.

It is important to note that the division between integrated and complex characters is not definite in all cases. For example, the earlier mentioned character 美 is composed of two radicals and is a semantic complex character. However, it is mostly recognised as an integrated character because the two radicals it comprises are integrated with each other and not able to be separated. Also in some cases the character 美 is a phonetic radical such as in the character 鎂 ('mei3', magnesium).

Words and Morphemes

Up to the word level, the units making up a Chinese word are a single character or multiple numbers of characters. Two-character words outnumber one-character words 2:1, with multi-character words constituting less than 2% of the total. A morpheme is the smallest meaningful unit in the grammar of a language. In ancient times a character represented a single morpheme; however, in time the one-character words did not continue to offer an adequate vocabulary, and there thus naturally emerged the two-character or multiple character combination (Fang, 1994). Whereas one-character words, such as 妻 (pronounced as: chi1, meaning: "wife"), are still used in modern Chinese, two-character words are the most numerous kind of multiple-character words. Two single characters which together make up a word can be morphemes themselves when they appear separately. For example, 水果 means "fruit", but individually the characters have their meanings: 水 means "water" and the second character 果 means "seeds of plants". In some cases, the stand-alone characters do not have a concrete meaning of their own when separated, for example, the two single characters in the word 葡萄 do not individually stand for any meanings; only when they are combined together do they represent the fruit "grape". Effectively characters like 水 and 果 are morphemes themselves, whereas 葡 and 萄 are not.

Three-character words like 水蒸汽 ("water steam") were made by a one-character word 水 ("water") and a two-character word 蒸汽 ("steam"). This combination of morphemes is a one-character morpheme plus a two-character morpheme. A three-character word can consist of a two-character morpheme plus a one-character morpheme, or simply a three-character morpheme, though this last type accounts for only a small percentage of words. Two-character words are the largest proportion of Chinese words. Words of more than five characters are really rarely seen today. However, some four-character words like 水上人家 ("boat dwellers") and five-character words like 電子計算機 ("electric calculator") are used commonly in modern Chinese.

1.2. Normal/unlateralised Chinese reading

1.2.1. The characteristics of Chinese

In summary, more than 80% of Chinese words are phonetic complexes (形聲字), which comprise both semantic and phonetic information in a character. The orthographic, phonological and semantic information are often seen as being integrated in square orthographic structures at similar spatial scales. This dense information contained in characters is considered as being richer and fuller than alphabetic letters and Japanese *kana*. The characteristics of the Chinese writing system can be summarised in the following points. (a) A Chinese character is a monosyllabic unit, and in ancient times a character was a morpheme itself. (b) Chinese characters are highly homophonic. The pronunciation of Mandarin Chinese is made up of consonants, rhymes and four tones. Perfetti, Liu and Tan (2002) reported that, on average 11 characters share a pronunciation. (c) The majority of characters are phonetic complexes, and the position of the radicals is such that phonetic radicals are mostly on the right and semantic radicals on the left. (d) The compositional structure of a Chinese word is hierarchic and clearly defined, based on strokes, stroke patterns (radicals), characters, and through words to sentences. (e) The inter-word and intra-word spaces of Chinese are equivalent, which often causes ambiguity when deciding word boundaries in sentence reading. (f) Chinese has three normal orientations. They are: horizontal from right to left; horizontal from left to right; and vertical from top to bottom, with the first line in the right and the next line and following lines to the left of the fist line.

Chinese orthography is radically different from English, consequently the early processing of orthography is commonly presumed to be different in the two languages. This issue will be discussed in the later sections; at this point we will review studies concerning the development of reading.

1.2.2. Developmental processes in reading Chinese

In developmental theories, there are some three different stages in the process of learning to read alphabetic languages (Marsh, Friedman, Welch, & Desberg, 1981). Together with Chall (1983) and Rayner and Pollatsek (1989), the developmental theories can be summarised as follows. (a) Linguistic guessing and Discrimination net guessing, or as Chall (1983) termed it, the Pre-reading stage (before 6 years old): in this stage learners start to use visual and graphemic cues such as word-shape to recognise symbols and letters; (b) Sequential decoding, or Initial reading stage (6 to 7 years old): in which learners use the orthographic cues and the grapheme-phoneme correspondence cues to relate the basic orthography, phonology and semantics; and (c) Hierarchical decoding or Automatic recognition stage (7 to 9 years old): in which learners develop the processing units and develop mature word decoding and recognition skills.

In normal Chinese reading, Won (1991) also specified three stages in the learning process. (a) Relating stage: Chinese learners start to build up a rough, temporal correspondence of the orthography, phonology and semantics of Chinese characters. Yet, this relationship between the three types of information is unstable, ambiguous and incomplete. Errors at this stage occur mostly because of wrong radical positions and the lack of strokes. Character replacements often occur at orthographically, phonologically or semantically similar characters. (b) Initial discrimination stage: Chinese learners are confident of the basic structure of Chinese word shape, but not the fine-grain compositional rules. The majority of errors occur from guessing and wrong recognition of characters. (c) Fine-grain discrimination stage: Learners are fully familiar with the radicals, the compositional rules of characters and the correspondence of orthography, phonology and semantics for 90% characters taught. Also they are able to recognise/discriminate a character from others by semantic information.

1.2.3. Learning to use orthographic cues

It is acknowledged that the developmental stages of learning to read Chinese are similar to those found in English (*c.f.* Hung & Chen, 1997; Won, 1991). However, Yeh et al. (Yeh & Li, 2002; Yeh, Li, Takeuchi, Sun, & Liu, 2003) stated that Chinese learners adapted different strategies while doing a visual similarity judgement. While beginners focus more on the components, strokes/radicals that characters shared in common, skilled readers tended to rely on the overall configural structure for the visual judgement. Non-skilled Chinese readers have to learn the configural structures of Chinese before being skilled in reading. Yeh et al. also pointed out that this structure is not developed merely upon the maturation of age, but upon learning and experiences (Yeh et al., 2003). It seems that radicals function more easily as orthographic cues in certain tasks, compared with characters. The systematic composition of Chinese words from radicals has built up the complexity of Chinese words.

A lot of recent Chinese studies adapting the methodology of English-based research concern the issue of the Word Superiority Effect (WSE). The WSE was first reported by Cattell (1886) to test the use of orthographic cues by English learners. Observed in a letter-searching task; the WSE showed that in a short presentation condition, searching for a letter which was embedded in a realword was easier than searching for it in a nonsense word, or even easier than when the letter was singly presented. Also such searching was easier in a high-frequency word than in a low-frequency word (Johnston, 1981). Mason (1975) conducted a letter-searching experiment with young English learners and confirmed the WSE in 11-year-old participants who had good reading performance. However, participants with poor reading performance have not shown the effect.

Ko and Wu (1987) examined the WSE in Chinese orthography with nonwords, pseudowords and real words using a similar method. He found that the ability to use orthographic cues developed during the age of 7~9 years. The 7-year-olds could recognise Chinese characters, pictures and symbols; and they learned to recognise nonwords, pseudowords and real words during the later two years. Huang (1993) reported that Chinese learners aged 7 and 8 were able to recognise pseudowords, but they were neither very skilled in using orthographic cues, nor familiar with the compositional strategy in Chinese. Not until they were 9 years old could they develop the compositional strategy of Chinese orthography and be able to recognise low-frequency words and pseudowords.

The developmental processes of Chinese reading suggest that the learning process of Chinese is established step by step, akin to those of learning to read English. However, there are critical characteristics which differentiate the Chinese and English reading process, such as the unique information profile in Chinese characters. A Chinese word can contain either a single character or multiple numbers of characters. Some Chinese characters are morphemes themselves - they represent sensible meanings and can stand on their own;

others are not exact morphemes themselves - they have incomplete meanings when individually presented, and need to accompany other characters to make a word. Thus the WSE in English when implemented in Chinese has been finely differentiated to be either Chinese character superiority or Chinese word superiority.

1.2.4. Word superiority and inferiority effects and the Interactive Activation framework

Psychological studies in the field of Chinese reading regarding WSE were mainly led by Cheng since 1981 and presented in literatures written in Chinese (Chen, 1984, 1987; Cheng, 1981; Hue, 1989). They can be summed up as follows. Cheng (1981) first confirmed the WSE in Chinese, and he also stressed the roles of word frequency and complexity in Chinese. He reported that the Chinese WSE was restricted in low frequency words, and it was very much affected by the degree of complexity (defined as the number of strokes in a word), instead of a simple superiority of realwords over nonwords. Hue (1989) also reported the WSE in which Chinese readers performed better in a character-naming task when required to read the first character of a singly presented realword, compared with the condition where a nonword was singly presented. More interestingly, word length (two- or four-characters long) affected the character-naming latency of both high and low frequency realwords, such that Chinese readers performed better in two-character words than in four-character words. But this effect was not found in nonwords. Hue (1989) suggested that the recognition of realwords might be of assistance to the recognition of characters, thus when presented with a realword, participants may have experienced a unitization process of the whole word and hence be sensitive to word length.

Apart from the WSE, there is a Word Inferiority Effect (WIE) which represents the difficulties in searching for a particular letter among realwords, compared with nonwords (Healy, 1976). Hue (1989) further replicated the WIE and found that Chinese readers detected a two-character nonword better than a two-character realword, when the orders of the characters were wrongly transposed in a normal paragraph. Chen (1984, 1987) tested the Character inferiority effect in Chinese by carrying out a searching task where Chinese readers were required to circle the radical '日' in a short paragraph comprising several hundreds of Chinese characters. Chen found that the probability that readers mistakenly neglected the target radical in high frequency characters was significantly higher than that in low frequency characters.

The WSE and WIE effect in reading seem to stand in contrast with each other, in fact, they represent different levels of processing in the same model, and there is an interactive model which offers a plausible explanation of the processes. An interactive modelling framework (Fang, 1997; Healy, Oliver, & McNamara, 1987; McClelland & Rumelhart, 1981) indicates that in word recognition, readers perceive the features of a word at various perceptual levels (for example, letter shape, word shape, etc). When the featural analysis of a certain level is completed, it would improve the analyses at other levels. Cattel (1886) explained the WSE as that the activation of low-level letters may have been increased by the activation of high-level words, such that the letters become more easily activated, compared with the non-activation condition.

The Interactive Activation framework has been more commonly recognised as a reasonable explanation for both the WSE and the WIE. The Interactive Activation framework suggests that word recognition is achieved on the basis of featural analyses, which are carried out at both high and low levels in the process of reading. Once readers finish the featural analysis at high levels, they would no longer analyse low-level features, but keep on analysing the next word. Take the character '日' for example. In studies concerning the WIE, readers searched for the radical '日' among words such as '時間...' in a paragraph. As the word '時間' is a very high frequency word, it is naturally easy for the high-level '時間' to be recognised earlier than the low-level radical '日'. Effectively, the radical '日' is neglected and readers carry on processing the next word and this is an inferiority effect. On the other hand, in WSE studies word stimuli were always presented individually, so there was no 'next' word for further analysis. Readers may interactively process the low-level features and receive information and feedbacks from high level processing, and therefore elicit the Superiority effect.

Cheng's report in 1981 not only confirmed the WSE existing in Chinese but also suggested that, analogous to English, the processing of Chinese word recognition is seen fit to be covered by the Interactive Activation framework.

Levels of activation

As far as the order of featural activation is concerned, there have been studies offering different models (Hue, 1989, 1992; Perfetti & Zhang, 1991). Hue reported that in high frequency Chinese words, the activation of a word (a high-level featural processing) is not required to go through the activation/processing of the low-level Chinese characters it comprised. As reported earlier, Hue's study (1989) has shown that the latency of reading the first character embedded in words is determined by their wordness: whether the presented word is a real-, pseudo-, or nonword. However, at the character level, the naming latency of a low frequency character is very much influenced by the lower-level components: its phonetic radicals, suggesting that the low-levels can be activated before the high-levels (Hue, 1992). The processing is rather affected by word frequency, suggesting the important status of the frequency effect in Chinese character recognition. Kuo, Yeh, Lee, Wu and Chou et al. (2003) reported an fMRI study reflecting more demanding processing and more activated brain regions for low frequency characters than for high frequency characters.

Learning phonological regularity in Chinese

Learning phonological regularity in Chinese is critical for Chinese beginners, as the phonetic radicals of complex character usually provide a cue for the pronunciation of characters. Only 38% of characters sound identical to their phonetic radicals. The acquisition of script-phoneme mapping is developed through sequential stages involving phonological regularity. Chen, Shu, Wu and Anderson (2003) and Li (2002) found that young children aged 7 and 8 performed best with fully regular characters. Children gradually learned semi-regular characters and their phonetic families at the age of 10.

1.2.5. Early construction of orthography and native language background

Orton (1937) stated that reading development requires children to disengage posterior non-linguistic RH visual representations and processes that interfere with proper word identification, at least in left-to-right alphabetic orthographies. The development of reading increases the activation of regions in the LH and decreases the activation of the RH (Turkeltaub, Gareau, Flowers, Zeffiro, & Eden, 2003). Dyslexia studies also showed that impairments in reading usually related to an abnormal activation in the RH, whereas control children relied on the LH phonological decoding circuit for reading (Shaywitz, 2002). The dyslexics tend to have their preferred viewing location (PVL) lying more leftward to the fixation, compared with the average PVL observed in non-dyslexics (Kelly, Jones, McDonald, Shillcock, *in preparation*). These findings demonstrate that the RH may play an important role in early reading and language acquisition.

Additionally, it was reported that visual field asymmetries in recognising individual letters in words were observed starting from 7-year-old, and effects of word familiarity starting from 8-year-old (Aghababian & Nazir, 2000). These aspects of adult reading skills were attained very early during reading acquisition in the native language. Furthermore, brain/anatomical differences can be driven by the system-level organisation of linguistic functions attributable to native languages such as English and Chinese (Kochunov, Fox, Lancaster, Tan, & Amunts et al., 2003). Kochunov et al. used fMRI to inspect the brain activation of English and Chinese speakers. They reported that the brain activation and brain regions activated are different in these two groups. There is a plasticity which allows human brain to be configured in accord with the native languages that people use.

The brain seems to be configured to the native languages (L1) one acquires, but it is interesting to know how a second language (L2) asserts itself in the brain and in the reading process. For two languages such as English and French, it is recognised that they are similar languages sharing many common features (*c.f.* Ziegler, Perry, & Coltheart, 2003). Further, for two radically different languages such as English and Chinese, the L2 inevitably interacts with and is constrained by the L1 (Tan, Spinks, Feng, Siok, & Perfetti, 2003). Tan et al. inspected with fMRI the brain activity in the processing of Chinese and English by bilinguals. They found that logographic Chinese associates activations in the left middle frontal and posterior parietal gyri, cortical regions that are known to contribute to spatial representation and coordination of brain resource. On the other hand, the processing of English by these Chinese-English bilinguals lacked strong activations in regions relating to the fine-grained phonemic analysis observed in English monolinguals. In theme one in this thesis, we are going to investigate the English concrete and function word dissociation in Chinese-English bilinguals and examine how the information profile in English and the direct access to syntactic processing in the LH would assert themselves in people with a radically different native language background (Chapter 4).

1.3. Models of orthographic, phonological and semantic processing in Chinese

The processing of orthographical, phonological and semantic information has been intensively studied in Chinese reading. Since 1990s, Perfetti and Tan have carried out a series of studies especially regarding these issues. We will review the studies of information processing and the insights learned from recent brain-imaging studies in the following sections. Once we finish the reviews of normal processing in Chinese reading, we will discuss the lateralised processing in both English and Chinese literature in Section 1.4.

1.3.1. Orthographic processing

Looking at the complexity of Chinese orthography at the word level, Yang and McConkie (1999) showed that the recognition of two-character Chinese words was not as sensitive to fixation location as was the recognition of words from alphabetic languages. Instead, during the reading of Chinese, eye fixations fall equally onto the characters themselves and into the inter-character spaces. Tavassoli (2002) compared Chinese and English orthographies by distorting the radicals in Chinese logographs and the letters in English words and tested the memory for spatial locations in native and bilingual readers. The results showed the spatial memory was better for Chinese characters than for English words, in both native bilingual groups. As previously shown, the equal inter- and intra-word space is a feature of Chinese orthography. Hsu and Huang (2000) analysed the inter- and intra-word intervals in speech production of Chinese reading. They found the space between words had longer intervals in speech than space within words. Furthermore, enlarging the space would lengthen the interval time of reading.

If word recognition is based on single characters, there is a position effect for radicals. First, the upper part of characters is more crucial for character recognition than the lower part (Liu, 1983). Liu explored this issue of positional information with a masking paradigm. He divided a single character into four quarters, removed one quarter of the character, and asked participants to read sentences comprising the transformed character. Then Liu analysed the error rates of participants' sentence-reading and found that when the missing quarter of characters was located in the upper half of characters, the number of reading errors made by participants were more than the condition where the missing quarter was in the lower half. Effectively, the upper half of a character provides more essential information for reading than the lower half.

Second, comparing radical (or the stroke patterns) with strokes, Chen et al. (1996) showed that the recognition of single characters depends more on the radicals than individual strokes or the number of strokes. Developing the structure awareness of radicals improved the learning of Chinese reading (Lam, Ki, Lan, Chung, Ko et al., 2001). Again, positional information is crucial in activating radicals during Chinese character recognition (Ding, Peng, Taft, 2004; Taft & Zhu, 1999; Tavassoli, 2002). Taft and Zhu used twenty-two pairs of characters that shared two identical radicals that can be transposed and still form a real character, such as the characters 呆 and 杏. They then made up non-character stimuli by switching the untransposable radicals and asked participants to carry out a lexical decision. Results of response latencies showed that the character 呆 was never confused with 杏 even though they contained the same radicals. It was also suggested that the radicals in a character were inevitably activated. Both the featural and the global information, such as the relative positional information, were encoded during the task (this is an important basis of Chapter 8, experiments on "grotesque characters"). Third, activation only occurred in complex characters or when the number of identical radicals that two characters share was at least half of the total number of radicals (Ding et al., 2004; Taft & Zhu, 1999). In the case of complex characters (consisting of two or more integrated characters), activation occurs only when the identical parts were more than two radicals. Similar effects were replicated by Fang and Wu (1989) in a probe/radical detection task: the radicals in one single character would affect the activation of the same radicals contained in other characters, though this activation does not stop the readers recognizing the later characters (i.e. the broad configural coding remains). Yeh and Li (2004) reported sublexical processing in visual recognition of Chinese characters by studies of repetition blindness. They found that Chinese readers lost the ability to report two characters when the two shared a similar or identical radical. Such blindness was effective, especially when the exposure duration of the two characters was shorter than 50ms, compared with the controls with no shared radicals. These studies have shown the critical status of radicals over other units in the processing of Chinese orthography involving sublexical-level processing.

1.3.2. The arguments about phonologically mediated processing

(a) Non-phonological pathway.

It was initially hypothesized that the reading of Chinese may go directly from visual orthography to high level semantics, given that Chinese originated from pictograms. This is the direct lexical hypothesis. Different methodologies have been developed for the study of this non-phonological pathway. This non-phonologically mediated processing was first described by Tzeng and Hung (1978). They assumed that if a task does not involve the phonological pathway, then doing a task like naming digits at the same time should not affect the particular task. Their results showed that participants could perform well even when they were naming irrelevant digits and carrying out a visual matching task simultaneously. However, when doing a task like fluency judgement or rhyme judgement, participants were severely distracted if asked to perform a digit naming task simultaneously. Apparently the latter three tasks crucially require phonological access at the same time, but visual matching task does not. We suggest this non-phonological pathway might merely represent a processing in lower visuo-spatial modes. Zhou, Shu, Bi and Shi (1999a) and Chen and Shu (2001) provided more convincing evidence. Zhou et al. used a priming paradigm and carried out a series of experiments to examine whether there is a phonologically mediated priming effect and whether phonological access plays a role preceding semantic activation. They used different sets of two-character words with semantically related primes as well as homophone primes, pseudo-morphemes and nonword controls as stimuli for a priming and lexical decision task. The results showed that the semantic priming effect is overall the strongest effect, whereas the homophone priming was not significant except in naming tasks. Furthermore, there was no evidence for phonologically mediated priming between lexical access and semantic activation (Chen & Shu, 2001). They suggested that the lack of phonological mediation is not due to competition between homophones at the semantic level, but to the genuinely limited effect of phonology on semantic activation. They reported these findings were true also for Chinese single characters as well as for two-character words.

(b) Phonologically mediated processing.

In contrast to the non-phonology pathway, Weekes, Chen and Yu (1998) reported phonologically mediated processing with more carefully controlled single-character stimuli. This processing is similar to the phonological recoding hypothesis. Weekes et al. showed that phonological and semantic activation occurred at the same time during the recognition of complex characters. Semantic priming effects were found in both complex and integrated Chinese characters, whereas phonological priming effect was found exclusively in complex characters. Similarly, Weekes and Zhang (1998, 1999) further reported phonological priming effects with complex characters, but restricted to the RVF (LH). Their finding suggested that phonological processing occurs in visual character recognition, at least for complex characters. Also it is thus beyond dispute that the recognition of Chinese characters involves a decomposition process in which phonological and semantic information are extracted from the ideographs.

(c) Phonological and semantic mediation.

Another methodology for studying phonological and semantic mediation is the Stroop paradigm. Spinks, Liu, Perfetti and Tan (2000) presented research in which they used colour patches and characters with different colours for a colour naming task. Together with the colour, three types of character stimuli were used; they corresponded to the name of a presented colour in different ways and showed different effects. For example, for naming the colour 'green': 綠 (lu4), the homophone, such as 慮 (lu4, 'consider'), resulted in a facilitation effect and indicated phonological mediation of the colour naming task. Likewise, characters that had the same pronunciation but a different tone, such as 旅 (lu3, 'travel'), also facilitated the task; this result indicated phonologically mediated processing being driven by segmental phonology (i.e. the identities of the segments as opposed to the tone). Semantically related characters, such as 草 (tsao3, 'grass'), facilitated and mediated the task, but the effect was comparably less than with phonologically similar characters. The results mentioned above were compared with the results from a control character 涂 (tu2, 'a family name') that had no relation to the name of a colour.

(d) Homophones.

Recently, homophone effects in Chinese have been extensively researched, since Chinese has extensive homophony. As reported by Perfetti, Liu and Tan (2002) and based on the Modern Chinese Frequency Dictionary (Beijing Language College, 1986), the most frequently used 4574 Chinese characters share 420 distinctive syllables, disregarding tones. On average, 11 characters share a pronunciation and Chinese speakers use context to determine the meanings of a particular pronunciation. Studies have shown that the number of homophones of a character can affect phonological mediation in Chinese character recognition (Ziegler, Tan, Perry, & Montant, 2000). Ziegler et al. used three sets of stimuli with different levels of phonological frequency (i.e. the frequency of the spoken syllable irrespective of tone): high, low, and null, to test three tasks – lexical decision, immediate naming and delayed naming for an SOA of 120 ms. Results showed that, first, in the immediate naming task, characters with homophonic mates were named faster than characters without homophonic mates, which in turn had more errors than the other two groups. Secondly, no phonological frequency effect was found in the delayed naming task. Finally, a lexical decision was faster when a character had homophone mates (even if only a few) compared with characters with no homophonic mates. The influence of this phonological frequency could affect performances in lexical decision and immediate naming tasks. Ziegler et al. suggested that phonological representations are activated regularly as a part of word identification. More radically, they suggested that the core representation of the mental lexicon may be phonological, and then the acquisition of reading merely adds an orthographic interface to an already established lexical system that is speech-based. Additionally, the phonological frequency effect is based on specific-word frequency (i.e. the frequency of, for instance, *nun*) rather than on cumulative-homophone frequency (i.e. the sum of the frequencies of *nun* and *none*) (Caramazza, Costa, Miozzo, & Bi, 2001). This is true for English, Chinese and Spanish.

(e) Non-semantic pathways.

Weekes, Chen and Yin (1997) studied a Chinese anomic patient and reported that there was an advantage of oral reading over picture naming. They argued that oral reading in Chinese does not require access to the mapping between semantic representations and phonological output, but instead can proceed via a non-semantic reading pathway that maps orthographic representations onto phonological ones. This process would seem to correspond to the fact that, when reading low frequency Chinese characters, readers can correctly guess the pronunciation to some extent from the phonetic components contained in the characters without knowing their meanings. It is important to note that about 38% of phonetic complexes have identical pronunciations to their phonetic radicals. So recognizing a phonetic radical might be a good strategy for a skilled reader to achieve fast naming.

It is also important to note that oral reading and picture naming might involve separate processing, as Tzeng and Hung (1981) had suggested that picture naming and word reading employ different mechanisms. For a pictured object, access to the articulatory mechanism is apparently indirect. The concept for an object must be activated first and then the associated name retrieved for naming to occur. Tzeng and Hung stated that, on the other hand, a word appears to activate an articulatory mechanism before activating its concept, so reading a word is more of a direct process, compared with picture naming. Weekes, Chen, Hu, Yu, Xie and Cui (1998) reported a case study based on a Chinese patient who suffered from Anomia and Dyslexia. The patient showed a complete dissociation between impaired naming and intact oral reading of the same items, implying that, as Tzeng et al. and Weekes et al. suggested, picture naming and oral reading may rely upon functionally separate pathways.

1.3.3. Sublexical processing

If Chinese were ever processed through a non-semantic pathway, it might indicate a process below the lexical level. In the processing of English orthography, it is possible to process words sublexically at the letter level

(Rastle & Coltheart, 2000). However, Pelli, Farell, and Moore (2003) suggested that the sublexical processing is phenomenally effective in reading but it is not 'efficient' in storage. Orthographic representations of words are best stored and operated with 26 basic alphabetic units. Adding extra units such as the high frequency trigram 'the' is going to increase the complexity and enlarge the demand of processing. Hence, even the most frequent words are still represented in terms of their constituent letters. Pelli et al. reported the efficiency of word recognition and showed that the recognition efficiency for Chinese characters is lower than alphabetic words. There is no clear conclusion as to what the basic unit would be in Chinese. A unit as simple as a radical would have enormous varieties since there are 214 semantic radicals and 1499 phonetic radicals in Chinese (Perfetti & Tan 1999).

Phonology in Chinese is claimed to be activated at two difference levels: the word level and the radical level. Tan and Perfetti (1999) confirmed that segmental phonology and phonologically mediated processing exist but argued that the mediation occurs at the whole word level. They used homophones, synonyms and neutral words for a meaning-judgement task and a lexical decision task. Their experiment 1 showed that homophones took a longer time for the meaning-judgement. In their second experiment Tan and Perfetti used 2-character words that comprised a phonologically inconsistent character (i.e. the character has more than one pronunciation) for a lexical decision, and compared them with phonologically consistent characters. They found that words with a phonologically inconsistent character took a longer time to name. It is important to note, regardless of whether the phonologically inconsistent character occurred in the first or second position in a two-character word, the phonologically inconsistent character influenced the task to the same degree. This result indicates that phonology mediates word processing at a whole-word level, or at least is not influenced by character position.

Research against the view of whole-word level was provided by Zhang, Perfetti and Yang (1999). They found that in a semantic judgment task, the phonology of the whole character had an interference effect on the task, while in a homophone judgment task, only the phonemes of low frequency characters showed effects. Zhang et al. interpreted this result as showing that the phonology of radicals and characters were both activated in semantic and phonological tasks and the level of activation depended on the demands of the task. When doing a semantic task, the meanings, and the pronunciation of the radical level and the character level were all activated. However, the phonological activation of radicals is brief and is not crucial, so the activation of phonology at the character level dominates the result. In contrast, for a phonological task, such as homophone judgment, the activation of phonetic units is important, and thus activation at the radical level was necessary.

Perfetti and Zhang (1991) studied the activation order of the orthographic, phonological and semantic representation in characters. They reported that the representation of orthography is activated before the representation of phonology and semantics. Perfetti and Zhang manipulated the presentation of two characters with a methodology similar to a priming task. They found a significant improvement of character recognition when two characters were presented with an SOA of 30ms. The property these two characters shared must have activated the first character. The stimuli they chose to be second characters were orthographically, phonologically or semantically similar to the first character. Perfetti and Zhang reported that only the orthographically similar character improved the target character recognition with SOA 30ms. Another experiment of Perfetti and Zhang (1991) reported that with an SOA 50ms, all the orthographically, phonologically or semantically similar stimuli improved the target recognition. Thus the order of activation may be listed as, first, the orthographic information, and second, the phonological and semantic information.

In contrast to the research we discussed earlier, an experiment of Pollatsek, Tan, and Rayner (2000) reported that two single Chinese characters which had identical names reciprocally benefit even when one of them was perceived through parafoveal vision/previewing. Pollatsek et al. showed that the phonological codes and the phonological regularity are effective to the recognition of Chinese characters, whereas the orthographical and the semantic similarity of the two characters and the timing of presentations (in terms of preview, post-view conditions or a simultaneous viewing condition) are not as effective. The study of Pollatsek et al. was more concerned with the information processing of Chinese, rather than developmental observations or the model of word recognition. It relates to our study in terms of the issue of parafoveal information, which we will present in the experiments of the Overlap and Pop-Out effects in the later chapters.

1.3.4. Morphological and syntactic processing in Chinese: studies of impaired processing of Chinese aphasia

Chinese syntactic processing involves a segmentation procedure on the basis of its semantic unit – morphemes – because of the equal space between and within words. While the temporal scale of natural segmentation from characters to words based on behavioural data is still unclear, recently many studies of computational linguistics have adopted statistical approaches, neural network and corpus-based strategies to model the segmentation performance of Chinese readers or to improve machine learning on hand-written text. The major challenges in Chinese segmentation lie in (a) Chinese text lacks word delimiters, (b) ambiguities of word boundaries, and (c) the occurrences of out-of-vocabulary words (i.e. unknown words) (Yang & Li, 2003). Many studies dealing with the problem of word segmentation have focused on the resolution of segmentation ambiguities.

One issue which is critically important in this thesis is the ambiguity of word boundaries and the Preferred Viewing Location (PVL) in Chinese reading. Researchers have been interested in the process of how the text string is segmented into words during reading, given that the intra- and inter-word space are equivalent in Chinese orthography. Three avenues were given by the literature. First, as two-character words are the most common length in Chinese orthography, Inhoff and Liu (1998) provided a two-by-two strategy, by which Chinese readers could direct their eyes to the next two characters to the right while reading horizontal texts. However, this two-by-two parsing can not always be correct due to the common existence of one-character and three-character words. This strategy must have involved frequent reverse-saccades and reparsing of sentences to achieve the best processing.

Secondly, an English-based study by Rayner, Fischer and Pollatsek (1998) showed that removing inter-word space would lengthen the reading of alphabetic text, and the preferred viewing position of English readers changed to the beginning of words (i.e. the end of the last word). However, Chinese studies have had controversial results when varying the Chinese word space. While Liu, Yeh, Wang and Chang (1974) reported that extending the spaces between Chinese words did not facilitate the reading, Hsu and Huang (2000) stated that enlarging inter-word space lengthens the interval time between words in reading.

Third, perceptually Chinese characters are different in their outer shapes (Yeh, 2000; Yeh & Li, 2002). Thus, selected characters may serve as saccadic targets (Tsai & McConkie, 2003). Given the fact that a Chinese character is a natural unit that never confounds its boundary with others, fixations on characters seem advantageous in reading Chinese orthography. Yet, this fixation strategy is not optimal in terms of processing efficiency. Yang and McConkie

(1999) suggested there to be no PVL in Chinese reading (*c.f.* section 3.4.3 in this thesis). At the same time they found a word frequency effect which might direct the eye fixation in terms of skipping or refixating words. Furthermore, they found the landing position of eye fixations to be a normal distribution, indicating little effect of word length. In short, Chinese orthography does not appear to have a PVL phenomenon analogous to English. If Chinese adapted the landing position distributions similar to English, it was suggested by Tsai and McConkie that the distribution would extend far beyond the character edges, and cause overlapping distributions for adjacent characters.

The best analogue, if any, to English processing would be Yang (1994), in which Yang found that two-character Chinese words are less likely to be refixated following an initial fixation near their centre, compared with an initial fixation farther from their centre (McConkie, et al, 1989; O'Regan & Jacobs, 1992).

Finally, the fine grain information in Chinese characters, such as the complexity and the information profile might have spread the saccade targets to some positions within characters (Tsai & McConkie, 2003).

Aphasia studies

The majority of studies concerning morphological and syntactic processing are from neural, clinical evidence. They are not as systematic as research into phonological and semantic processing; most of them are individual single-case studies with specific syndromes and treatments. Chinese aphasia has been intensively studied in the recent two decades. The topics span from Aphasia and Agrammatism (Bates, Chen, Tzeng, Li, & Opie, 1991; Chen, Tzeng, & Bates, 1992; Tzeng, Chen, & Hung, 1991; Yang, Yang, Pan, Lai, & Yang, 1989) to specific Agrammatism (Lee, 1987; Lu, 1994; Packard, 1990; Su & Luo (1992), Yiu & Worrall, 1996a, 1996b), Crossed-aphasia (April & Han, 1980; April &

Tse, 1977), Global Aphasia (Chen, Liu, Hsieh, & Lien, 1994), Conduction Aphasia (Chang, Hu, Lien, Chen, & Hsu, 1986), Chinese Aphasia assessment (Yiu, 1992), and other speech errors in Chinese (Whitehill & Ciocca, 2000; Yiu & Fok, 1995).

We review the most important aphasia studies as follows and will review issues of crossed-aphasia in section 1.4.4, Lateralised syntactic processing in Chinese.

Nouns and verbs involve distinct brain regions

Bates, et al. (1991) and Chen et al. (1992) studied the noun-verb problem and sentence interpretation in Chinese aphasia. They took Wernicke's aphasia into account and compared it with Broca's aphasia. The analysis of different disruptions of nouns and verbs in different forms of aphasia showed that Wernicke's aphasia patients demonstrated an advantage in action naming, whereas Broca's aphasia patients demonstrated more often 'attempt lexicalization' in object naming. Bates et al. suggested that the different disruption of nouns and verbs in different forms of aphasia reflects the spatial organization of those brain regions that are responsible for lexical processing. Additionally, patients with verb retrieval problems are often able to produce an alternative way that captures the same basic event structure. This finding is also reported in Chen et al. (1992) that the semantically based strategy is resistant to breakdown in sentence comprehension by fluent and non-fluent aphasics. This means that the agrammatics are able to control the semantic features that underlie naming tasks.

In Chen et al. (1992), Broca's aphasia is regarded as the central type of agrammatism, due to their selective inability to use grammatical cues in language comprehension and production. Agrammatism is characterized by patients' good auditory comprehension ability, but their speech production is non-fluent, and they may omit function words (see, e.g., Packard, 1990). Wernicke's aphasia has been regarded as Paragrammatism. Paragrammatic speech may be fluently produced by aphasic patients (Packard, 1990). They are relatively free from impairments in the use of grammar, but have impairments in auditory comprehension ability, and their production shows a disruption in the use of open class items such as errors on the suffixes of nouns and verbs (content words).

Relatively free word-order in Chinese

Lu's thesis (1994) presented the most detailed study of Chinese agrammatism in terms of its clinical features. Chinese-speaking agrammatic patients share many common symptoms with agrammatics in other languages, such as using short and simplified syntactic structures, or in severe patients, fragmented utterances composed of only nouns or aberrant word orders. Apart from these deficits in the basic process of syntactic form generation, Chinese agrammatics took advantage of the relatively free word-order in Chinese (Lu, 1994, both NVN or NNV word orders are both normally used in Chinese) that they could try to arrange the available words in an order that is acceptable in Chinese, although they still omitted verbs and produced fragmented sentential constituents. Morphologically, Chinese-speaking agrammatic patients had difficulty producing grammatical morphemes and might make omission and substitution errors (Packard, 1990; Tzeng, Chen, & Hung, 1991). Unlike what Packard (1990) predicted - that there would be no substitution errors in Chinese-speaking agrammatics because there is no inflectional system in Chinese (Lu, 1994) - substitution errors did occur in Chinese in the classifiers, case marker *ba* and *bei*, locative marker *zai*, and aspect markers *zai* and *le* (*cf.* also Chen et al., 1992). Lu noted that, compared to English patients, it is relatively difficult to find morphological errors in the free narratives of

Chinese-speaking agrammatic patients, because there are relatively few obligatory contexts for functional words. Patients can often find an alternative way to express the same grammatical function without using any grammatical morphemes that might be difficult to retrieve. Lu also noted that the performance of Chinese-speaking agrammatics generally scored better in batteries than patients in English. It might be due to the different severity of the patients in different studies, and the lack of an inflectional system in Chinese.

Further to the broad study of agrammatism, Lee (1987) reported a case study in terms of the disruption of sentence structure. She summarised the structure of Chinese sentences in the following three points. First, Linear structure: sentences constitute a linear structure which is made up of a regularised word order. A sentence with wrongly transposed word orders is not appropriate for communication. Second, Layered structure: the phrases in sentences should be parsed according to the relationships with each other. A sentence such as 'my brother has bought that book' can be parsed as 'my brother – has bought – that book' but not 'my – (gap) – brother', 'has – (gap) – bought', or 'that – (gap) – book'. Third, Grammar: the basic structure of sentences is a noun phrase followed by a verb phrase. The noun phrase can be a noun, a sentence, or a noun phrase plus a sentence; and the verb phrase can be a verb, a sentence, or a verb phrase plus a sentence. There are also various sentence styles made up of various combinations of phrases. Lee analysed the sentences spoken by a Chinese agrammatism patient and categorised incomplete sentence structures on five points: (a) a wrong word order, (b) lack of function words, (d) lack of verb phrase, (e) lack of the changes of sentence styles (*cf.* Lee, 1987 for further rehabilitations strategies).

Su and Luo (1992) reported a case of Chinese agrammatism in terms of the performance of syntactic comprehension. Su and Luo found that the presumed 'incomplete syntactic representation' based on English studies (Grodzinsky,

1990) was not found in the Chinese subject. However, the absence of the presumed syntactic error of 'moved phrases' might have been due to the individual difference of this patient, or because the passive sentences in Chinese do not involve much movement of noun phrases.

1.3.5. Insights from brain imaging technique and brain dysfunctions

Much recent work in Chinese word recognition has used brain-imaging techniques such as fMRI and brain dysfunctions such as neglect and dyslexia. These avenues of research go in three directions: first, cross-task differences. Second, cross-language differences of English-Chinese using various tasks and bilinguals.

(a) Cross-task differences

Phonological and semantic fluency task

Most recently, Kuo (2001), Lee (2001) and Lee, Kuo, Duann, Liang, Hung, Tzeng and Hsieh (2002), and Tarr, Williams, Hayward, and Gauthier (1998) have used fMRI to explore the neural basis of the recognition of Chinese characters and have indicated that the semantic fluency task involves the left fusiform gyrus, whereas the phonemic fluency task involves greater activation in the left inferior frontal gyrus. Their point is that the left fusiform gyrus might be related to the activation of phonemic and orthographic representations, whereas the left inferior frontal gyrus may be responsible for the rehearsal system of verbal working memory or for lexical access through a phonological route.

Characters and Chinese pinyin

Chen and Fu et al. (Chen, Fu, Iversèn, Smith, & Mattews, 2002; Fu, Chen, Iversen, Smith, & Mattews, 2002) examined brain activation during the reading of Chinese characters and Chinese *pinyin*. *Pinyin* is a phonological system using uniquely assembled alphabets to code and represent the pronunciation of Chinese monosyllables. For example, the 'zh' represents a consonant sounded similar to the first sound of the English word 'joe'. *Pinyin* does not have the script-to-phonology mapping of Chinese characters. Results showed that these two types of stimuli activated many common brain regions except that the inferior parietal cortex was more active for *pinyin,* and the fusiform gyrus for Chinese characters. There might be a broader network for processing written languages. Chee, Caplan, Soon, Sriram, Tan, Thiel, and Weekes (1999) also showed that the brain regions activated in the processing of Chinese sentences and the processing of single Chinese words are similar.

(b) Cross-task and cross-language differences

Reading aloud

Chee et al. (1999), Tan et al. (Tan, Feng, Fox, & Gao, 2001a; Tan, Liu, Perfetti, Spinks, Fox, & Gao, 2001b; Kuo, Yeh, Duann, Wu, Ho et al., 2001) reported that parts of the neural circuitry involved in reading Chinese are similar to what has been reported for reading alphabetic script. However, reading aloud Chinese words might be more closely associated with the activity of right hemisphere sites due to the fact that reading Chinese requires visuospatial and tonal analyses.

Generating verbs from nouns

A further study (Pu, Liu, Spinks, Mahankali, Xiong et al., 2001) extended from Chee et al.'s research and investigated the processing of English and Chinese based on a task of generating verbs from nouns in Chinese (L1)/English (L2) bilinguals. Pu et al. used an fMRI technique and showed that not only the regions involved in processing these two languages are similar, but also the magnitudes of signal changes were almost the same. It was concluded that the processing of Chinese and English languages were similar in Chinese-English bilinguals. Chee et al. (2000) explained this similarity of activation regions by the fact that both of the tasks above involved semantic processing. They suggested that it is the semantic processing that is processed in similar regions in the brain for both languages.

Synonym judgement and a translation task

Pu et al. (2001) and Ding, Peng, Jin, Ma and Luo (2002) were interested in the brain activation of bilinguals. They asked participants to carry out a synonym judgement and a translation task in within-language and between-language conditions by using mixed English and Chinese stimuli. The pattern of brain activation they found was similar to the pattern of a semantic synonym task. However, the translation task from English to Chinese caused more activation in the fusiform gyrus, compared with translation from Chinese to English. These data suggest that there is a common neural mechanism underlying the semantic processing of both languages, but that translation processing is asymmetric depending on which language readers learned first.

Semantic processing

Other research involving bilinguals concerns the processing of Chinese characters, English words, and pictures. Chee, Weekes, Lee, Soon, Schreiber, Hoon and Chee (2000) show that Chinese character recognition and picture processing produce differences in brain areas such as greater activation in the posterior temporal and prefrontal regions for Chinese, and greater activation in occipital regions for pictures. Similar patterns were observed when comparing English words and pictures. However, compared with pictures, English and Chinese seem to share similar regions for semantic processing, except that Chinese processing was associated with a larger MR signal change. This result stands in contrast to that of Hinojosa, Martin-Loeches, Gomez-jarabo and Rubia

(2000). Hinojosa et al. used an ERP technique to test the topography of the potentials evoked by pictures, English words and Chinese characters. They found the maximal amplitude at the left inferior parieto-occipital electrode for words and at the right homologue electrode for pictures and Chinese characters. Their interpretation was that these stimuli might share a multimodal region for the common semantic processing. However, Chinese characters and pictures more or less showed a RH lateralisation in processing.

These controversial studies individually showed an inconsistent result regarding the lateralisation of Chinese processing, as those in behavioural data. However, they are all options for the still unclear organisation of the brain and Chinese processing.

1.4. Hemispheric lateralisation and lateralised reading

Research and theories regarding hemispheric lateralisation have been growing for decades. Figures 5, 6 and 7 show the anatomical basis for research on presentational asymmetry. As shown in Figures 5 and 6, the relationship between the cortex and the eyes involves a contralateral arrangement, which initially allows inputs in the left visual field (LVF) to reach the RH, and those in the right visual field (RVF) to reach the LH. The crossover and projection from both eyes occurs at the optic chiasma, and the information going through the optic chiasma is led to the hemisphere contralateral to the eye. Thus when we focus on an object in our visual field, its left half is initially projected to the right visual cortex. Consequently researchers can present stimuli to whichever cerebral hemisphere they choose by presenting the stimuli in the right or left of the fixation point.

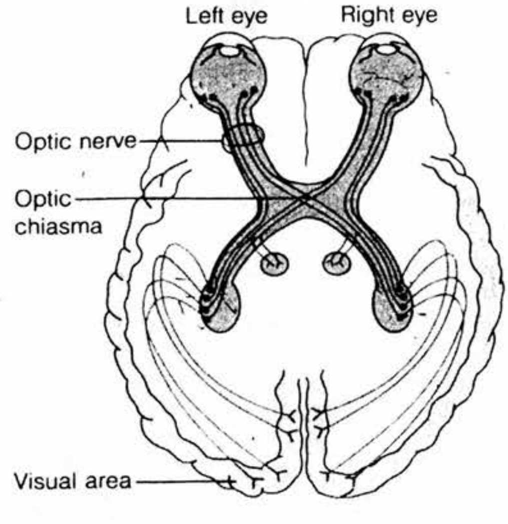


Figure 5. The optic nerve fibres and neural pathways leading from the retina of each eye to the primary visual cortex (reprinted from Springer & Deustsch, 1989).

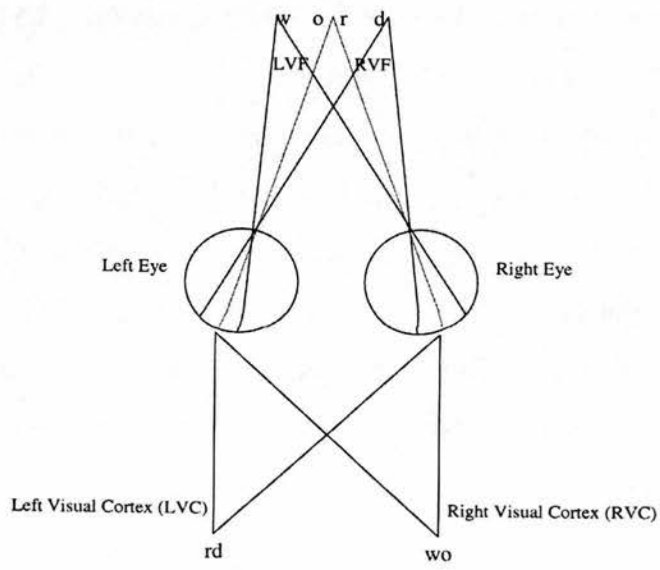


Figure 6. A contralateral arrangement. Stimuli falling on the right side of each retina are transmitted to the RH (reprinted from Springer & Deustsch, 1989).

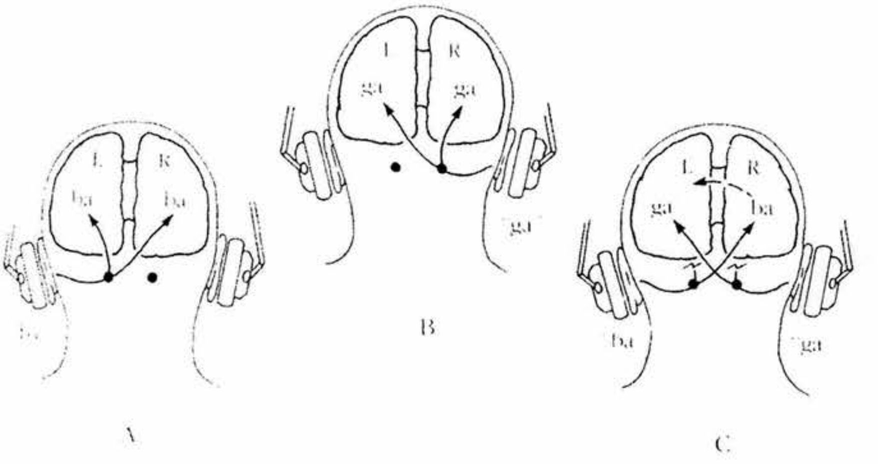


Figure 7. Kimura's model (1961) of dichotic listening in normal participants.

Studies of asymmetry in auditory lexical processing differ from these visual manipulations due to the anatomically different pathways. Figure 7 shows the typical design of dichotic listening experiments. A, B: Stimuli "ba" and "ga" are sent from the individual ears to both of the hemispheres, thereby allowing participants to report the stimuli accurately. C: When two stimuli are presented simultaneously, the ipsilateral pathways are suppressed. Information would initially reach the hemisphere opposite to each ear, and then those reaching the RH are further transmitted to the LH for a spoken response. Eventually, sounds input from single ears go through both of the hemispheres. In contrast, when discrete speech sounds are presented simultaneously in both ears, participants' reports typically show a right ear advantage. This outcome happens because when the two ears receive speech input, the pathways from one ear to the ipsilateral hemisphere are suppressed; information can only go to the contralateral hemisphere. In addition, speech input going to the RH requires an extra transmission to reach the LH, which is typically the dominant half of the brain for speech production. Thus when asked to recall the stimuli heard, split-brain patients would exclusively, and normal people would be more likely, to report the information obtained from the right ear. (Kimura, 1961; Zatorre & Belin, 2001)

Given the differential pathways of visual and auditory perception, researchers have used these pathways to explore how the two hemispheres are involved in language processing, both spoken and written language processing. Below we present the role of each hemisphere, in order of orthography, phonology, semantics and syntax. We will also review relevant Chinese studies in line with this order.

1.4.1. Lateralised orthographic processing

Language tasks (chiefly with alphabetic scripts like English) such as word naming, lexical decision and semantic categorization judgement are well known to produce a superior performance in the LH; whereas tasks involving visuospatial abilities, such as face recognition, pattern recognition, and perception of line slant, are typically performed better in the RH (see, e.g., Bradshaw & Gates, 1978, Moscovitch, Scullion, & Christie, 1976, Hellige & Cox, 1976, Bub & Lewine, 1988).

Lateralised orthographic processing in Chinese

First explored by Hatta (1977a), the LVF advantage for logographic symbols was found in Japanese *kanji*. This study demonstrated the LVF superiority for both concrete and abstract words, and in the LVF condition the recognition of concrete words was better than that of abstract words. Given the fact that Japanese *kanji* is a similar system to Chinese (Japanese has two distinctive writing systems) findings in Japanese *kanji* have important implications for Chinese orthographic processing.

However, in the intervening years, the claim of a LVF advantage for ideographic writings has not been consistently and fully replicated. Whereas Besner, Daniels, and Slade (1982), Zhang and Peng (1983), and Rastatter, Scukanec, and Grilliot (1989) all found a RVF advantage in the recognition of single characters, Cheng and Yang (1989) and Keung and Hoosain (1989) found a LVF advantage for single characters. One of the reasons was thought to involve the orthography issue. As previously discussed, and commonly known, Chinese orthography varies from pictorial to semantic and phonetic compounds. The differences in the pictorial characteristics of single Chinese characters compared with other types of characters may give rise to different processing (Nguy, Allard, & Bryden, 1980). Nguy et al. (1980) tested whether the RH is important in decoding ideographic forms of writing, and thus resulting in the LVF superiority, given the fact that the RVF advantage in studies of English reading had shown that the LH is typically specialized in the processing of words from alphabetic languages. Nguy et al. used pictorial single characters like 鬼, 桌, 鳥, non-pictorial single characters like 曼, 貨, 堅, and complex characters like 雄, 糖, 旅, as experimental materials. The methodology was to collect and analyse the accuracy data for each identification. The results showed that non-pictorial and complex Chinese characters had a clear RVF advantage, just like English words, whereas the pictorial single characters showed no differences between the two visual hemifields.

These results suggested two important avenues of research: first, pictorial Chinese characters which have a compositional strategy different from alphabetic English and other types of Chinese characters may result in a special kind of hemispheric lateralisation. Second, whereas the RH may not be better than the left in the decoding of ideograms, it does have sufficient capacity to eliminate the right field advantage for the processing of representational, pictorial ideograms.

Visuo-spatial features

This orthographic, visuo-spatial issue has been one of the most fascinating features of Chinese pictograms. It might be able to explain the Chinese-English differences in both the lexical and sub-lexical level, given the fact that the RH typically has superiority in dealing with visuo-spatial tasks. It is important to note that the two hemispheres carry out comparable low level cortical processing of visual information, but the RH is typically better at coding the spatial relationships of objects than the LH. For example, Davidoff (1977) and Grabowska and Nowicka (1996) showed that participants more accurately remembered the locations of dots presented on a card when the materials were presented initially to the RH. Also Levy and Trevarthen (1976) used a visual matching task to show that the strategies of the two hemispheres could be clearly differentiated: the RH may tend to match items directly in terms of their visual appearance, whereas the LH may tend to match items in terms of their underlying function. Further support was given by Gazzaniga and LeDoux (1978) with a within-brain test: the RH performed poorly in drawing a cube after a split-brain operation, compared with drawing performance of the same brain before the operation.

Further evidence has come from brain impairment studies concerning the crucial status of the RH in spatial ability. Patients with damage to the posterior parietal or parieto-occipital regions may present with unilateral visual neglect, in which they typically fail to attend to stimuli in the contralesional hemifield. In the classic line-bisection task (Butter, Mark, & Heilman, 1988; Sheppard, Bradshaw, Mattingly, & Lee, 1999), patients typically misjudge the perceived midpoint of a horizontal line as falling more towards the end of the line in the ipsilesional hemispace; that is, the damaged hemisphere has failed to perceive the full extent of the line in the contralesional hemispace. Although there is an approximate qualitative symmetry in neglect symptoms produced by damage to the two hemispheres – more or less similar, mirror-image impairments are produced by damage to either hemisphere – there are reliable differences in the detailed neglect behaviour produced by damage to the different hemispheres; for instance, there are detailed differences between patients' line-bisection behaviour depending on whether the damage is to the RH or the LH. Such differences present a challenge to an understanding of the hemispheric differences either in quantitative or qualitative terms. Overall, early research into unilateral visual neglect tended to be couched in terms of qualitative differences between the two hemispheres. For example, Posner, Snyder and Davidson (1980) and Corbetta and Shulman (2002) claimed that the RH alone typically contained a processing module which was responsible for disengaging attention; or Marshall and Halligan's (1995) claim that the LH's attentional processing was focused and the RH's was global. In more recent work (see, e.g., Pouget & Sejnowski, 2001; Monaghan & Shillcock, 2004), researchers have tried to explain hemispheric differences in neglect by saying that there are only quantitative differences between the two hemispheres.

In summary, effects of hemispheric superiority in reading have suggested a connection between spatial processing and orthographic processing for non-alphabetic orthographies. The RH superiority for spatial processing has been characterized in different ways by different researchers.

Visual complexity and spatial frequency in Chinese

In contrast to alphabetic or syllabic script, ideographs do not completely show a LH advantage; previously mentioned cases (e.g. Nguy et al, 1980) have shown an RH advantage or no difference in recognition tasks. It is important to note that the increase in visual complexity and spatial frequency are related to the development of hemispheric lateralisation (Besner et al., 1982; Coney, 1998). Besner et al. suggested that the LVF advantage in previous investigations may have been attributable to the stimuli containing a larger number of strokes; Besner et al. themselves used stimuli that in comparison contained fewer strokes on average, and thus showed a RVF advantage. This interpretation involving spatial complexity is supported by Coney (1998), though in the opposite direction. Coney reported no significant advantage for low-complexity characters, but a significant RVF (LH) advantage at higher levels of complexity.

To bring together what has been known about lateralisation and the visuo-spatial characteristics of Chinese characters, the Chinese orthography clearly shows its special nature. Although the complexity of English letters and Chinese characters is not comparable, it is generally acknowledged that Chinese characters are denser than English, at least in terms of counting pixels. Along with this denser structure, there are considerable differential contributions of orthographic, phonetic and semantic factors to visual word recognition in Chinese and English. The research is important at both the word and radical level.

In short, according to the RH superiority shown in certain visuo-spatial tasks and some brain impairments, Chinese character recognition is distinct from English word recognition due to its orthographic, pictorial or ideographic characteristics. These visuo-spatial characteristics along with the dense structure across not only the lexical level (words and characters), but also the sub-lexical level (stroke patterns and their positional information) affect the recognition of Chinese script, and accordingly the hemispheric lateralisation of the process. These effects make Chinese a so-called 'RH language'. It is important to note, although RH lateralisation is not always consistent, it has been recognised that the characteristics of Chinese orthography have been sufficient at least to eliminate some of the LH advantage found in other alphabetic languages.

1.4.2. Lateralised phonological and semantic processing

To review the great body of studies regarding the processing of phonology and semantics, we focus on those specifically concerning functional differences of the two hemispheres and hemispheric lateralisation. Some researchers have claimed that the RH is totally incapable of dealing with speech at a phonological level. For instance, in a task which required participants to select a figure that rhymed with a spoken word, the performance of participants' RH was at chance level (Levy & Trevarthen, 1977). Another auditory study by Zaidel (1978) has shown that the RH generally performed as well as a normal 10-year-old, when the patient's task was to match a picture with a single word spoken. In contrast, the LH typically appeared to have an advantage in processing speech. In a task involving distinguishing between speech sounds, such as "ba", "da" and "ga", which differ only in the first 50 milliseconds of the syllable, the LH showed superiority during the rapid presentation of the first 40 milliseconds of the speech (Schwartz & Tallal, 1980; Studdert-Kennedy & Shankweiler, 1970). When the changing frequency information was extended from 40 to 80 milliseconds, the right-ear advantage was significantly reduced by the improved performance of the left ear, though the performance of the right ear remained unchanged. These observations suggest that phonetic information is mainly processed by the LH, with partial contribution from the RH.

Binder, Frost, Hammeke, Cox, Rao, & Prieto (1997) used fMRI to identify areas processing spoken language in the intact human brain. The language activation task required phonetic and semantic analysis of aurally presented words and was compared with a control task involving perceptual analysis of non-linguistic sounds. Similar to classical models of language processing based on lesion data, cortical activation associated with spoken language processing was strongly lateralized to the left cerebral hemisphere and involved a network of regions in the frontal, temporal, and parietal lobes. They also found activations which were less consistent with classical models. For example, the existence of left hemisphere temporoparietal language areas outside the traditional Wernicke area and Broca area, and the lack of a clear participation of these left frontal areas.

Burton, Small and Blumstein (2000) used fMRI to investigate the activation of anterior (lateral frontal) areas in a speech-discrimination task involving consonants. In their experiments, participants were required to make "same/different" judgments on the first sound of word pairs. In the first experiment, the pair of speech stimuli varied in the initial consonant (e.g., dip–tip), and in the second experiment, the pairs of speech stimuli varied in initial consonant, vowels and final consonants (e.g., dip–ten). These speech conditions were compared to a control condition, tone-discrimination. Behavioural data showed that participants were highly accurate in both experiments, but revealed different response latencies. The imaging data indicated that whereas both speech conditions showed superior temporal activation, the second experiment showed consistent evidence of frontal activity. Taken together, the results showed that phonological processing does not necessarily recruit frontal areas, because the activation of these areas might be a product of segmentation in speech perception, or alternatively, these areas might be activated when working memory is being employed.

Horwitz, Amuntsb, Bhattacharyya, Patkin, Jeffries et al. (2003) used neuroimaging to study the left hemisphere activation of speech production. They showed that Broca's area in the inferior frontal gyrus consists of two regions—Brodmann areas (BA) 44 and 45. By using probabilistic maps of these two areas with functional neuroimaging data obtained by PET, they showed that BA45, not BA44, was activated by both speech and signing during the production of language narratives in bilinguals who were fluent from early childhood in both American Sign Language (ASL) and English, when the generation of complex movements and sounds was taken into account. In contrast, it was not BA45, but BA44, that was activated by the generation of complex articulatory movements of oral/laryngeal or limb musculature. The same patterns of activation were found for oral language production in a group of English monolinguals. These findings implicate BA45 as the part of Broca's area that is fundamental to the modality-independent aspects of language generation.

These findings confirmed the specialization of the left-hemisphere for phonological/phonetic processing, and indicated that certain areas outside Broca's and Wernicke's areas were especially involved in this process. Also, corresponding fields in the two hemispheres might be related and might have contributed to certain processing collaboratively.

As for semantic processing, the comprehension of word meanings may be severely disrupted after damage to posterior regions of the LH. In contrast, lesions in the corresponding area of the RH typically do not produce a similar deficit. However, the RH is able to comprehend certain concrete nouns such as "lock", "car" and "hospital"; at the same time, abstract nouns typically seem to depend more exclusively on the LH. Again, the right half of the brain seems to be involved partially and selectively in semantic processing. Since the LH can do the same or more, any deficit affecting semantics in the RH may be compensated for by the intact LH. Such data have convinced most earlier researchers how little the RH contributes to semantics (e.g. Hines, 1977). However, other researchers (e.g. Beeman, Friedman, Grafman, & Perez, 1994) have pointed to the possible advantages of the RH computing rather different semantic representations to those in the LH; in this view, the RH is predisposed to process coarser-grain representations, the LH finer grain ones, and labour is divided between the two.

Lateralised phonological and semantic processing in Chinese

When the processing of Chinese word recognition has been expressed by relatively abstract cognitive pathways concerning phonology and semantics, the interests of the researchers focused on three main issues. In the review of normal reading we have discussed the issues of (a) the arguments over phonologically mediated visual Chinese word recognition, and whether semantic representations might be contacted directly. (b) The issue of whether the radical or the whole word determines the activation level of the phonological representation. In the case of lateralised processing, studies stress the importance of (c) the difficulty level of tasks and its relation to hemispheric lateralisation and the Bilateral advantage.

Unilateral and bilateral advantage depends on difficulty and processing level

Leong, Wong, Wong and Hiscock (1985) argued that the unilateral versus bilateral advantage results from different processing levels in the recognition of single Chinese characters. They stated that tasks requiring participants to respond to a shallow level, such as orthography, or to deeper levels, such as phonology and semantics, changed the differential performances in the visual hemifields from a comparable level of accuracy to a strong RVF advantage. They claimed that the different pathways not only represent different levels of processing, but also involve activation in distinctive brain areas. Zhang and Feng (1999) further defined the levels in terms of computational complexity and replicated the result by using characters that were visually similar, homophones or synonyms. They reported that only in higher-level tasks such as phonetic matching (homophones) and semantic matching (synonyms) did participants show a bilateral advantage over unilateral presentation. Otherwise, within-hemifield and across-hemifield performances are comparably equivalent. It seems that phonetic and semantic processing are different from the visual/perceptual level, in that they also involve a higher and more complex level which gives rise to bilateral interhemispheric collaboration and mediation.

In short, studies regarding the issue of lateralisation and the Bilateral advantage have showed that the appearance of these effects is inconsistent. One of the factors resulting in this inconsistency has been the computational complexity of a task, including shallow *vs.* deep processing level and the degree of difficulty involved. Studies concerning the issue of phonological mediation have presented arguments about (a) a non-phonological pathway, (b) a phonology-semantics interface, and (c) a non-semantic pathway from orthography to phonology. The use of a different pathway in moment to moment reading seems to depend closely on the particular processing demanded by a task. For example, the non-phonological pathway was found in a semantic priming task, where phonology was not critical (Zhou et al., 1999a; Chen & Shu, 2001), whereas the non-semantic pathway was found in an oral reading task where semantics was not critical (Weekes et al, 1997). Or, tasks like digit-naming affect performance of the fluency task or the rhyme judgment task, but not of a task of visual matching (Tzeng and Hung, 1978). However, complex Chinese characters did show the extraction of both phonological and semantic information; so did the Stroop paradigm with Chinese characters in a colour-naming task (Spinks et al., 2000), and the homophone paradigm showed an effect of phonological frequency on lexical decision and on an immediate naming task (Ziegler et al., 2000). It was acknowledged that the processing of phonology is inevitable in visual Chinese character/word recognition.

As far as the activation level is concerned, it is argued that both the phonology of radicals and of characters is activated. Activation at the radical level is essential in homophone judgment, whereas activation at character level affects word recognition when the character is phonologically inconsistent. Furthermore, the fact that the two positions of a phonologically inconsistent character in a two-character word equally affect the processing of the word might suggest that the activation level is based on the whole-word level in some cases. We suggest that the factor that determines the occurrence of a Bilateral advantage is not the processing level such as shallow orthographic *vs.* deep phonological/semantic processing, but the complexity or difficulty level a task involves.

1.4.3. Lateralised morphological processing

It was commonly believed that both concrete and abstract English words were better recognized through the LH than the RH (Ellis & Shepherd, 1974). In addition, Bradley and Garrett (1983) reported that although there was an overall LH advantage for words, the RH still helped to identify words; but it identified function words less accurately than content words. Furthermore, Gazzaniga (1970) indicated that the RH was only able to process 'noun-object words' and a few adjectives, but no verbs or verb-derived nouns (e.g., 'teller' or 'locker').

Lateralised morphological processing in Chinese

As far as the topics of hemispheric lateralisation and the processing of Chinese morphology are concerned, the character-word dissociation hypothesis provided by Tzeng, Hung, Cotton, & Wang (1979) has been the most essential issue. Given that most prior studies had acknowledged the LH to be the dominant hemisphere in alphabetic language processing, the situation became more complex when nearly three decades ago Hatta (1977a) used both abstract and concrete non-phonetic logographic symbols (Japanese *kanji*) and showed that both concrete and abstract words were subject to an RH advantage. Kawamura, Hirayama, Hasegawa, Takahashi and Yamaura (1987), reported a patient with alexia and agraphia (caused by impairments in the left posterior inferior temporal gyrus) showing a deficit in processing *kanji* (Japanese morphograms) but not in *kana* (Japanese syllabograms). They speculated that *kanji* and *kana* might involve different intrahemispheric mechanisms. A more delicate distinction between the relevant pathways was also found. Another Japanese case reported by Yokota, Ishiai, Furukawa and Tsukagoshi (1990) suggested that writing *kanji* is even different from reading *kanji*, as they found a patient with pure agraphia who had severe impairment in writing *kanji* but on the other hand, writing *kana* and reading *kanji* and *kana* were almost intact.

Following Hatta's research of "RH languages" (i.e. those languages like Chinese and Japanese *kanji* that make substantial spatial processing demands), Tzeng et al., (1979) replicated the study and first introduced a character-word dissociation in Chinese: Tzeng et al. found a LVF superiority in the recognition of single Chinese characters, in both pictographs and phonetic complexes (Tzeng & Hung, 1978); more surprisingly, they found a RVF superiority in the recognition of two-character Chinese words (Tzeng et al, 1979). These studies done by Tzeng et al. have attracted many researchers to these issues. It is generally held that Chinese is an ideographic language that is distinct from alphabetic languages in many linguistic aspects. Three accounts are reported to explain the character-word dissociation.

Function-specific, lexical lateralisation hypotheses, and the differential perceptual degradation account

First, the function-specific hypothesis, proposed by Tzeng et al. (1979): the two hemispheres use their specialisations in processing characters and words. The RH is seen to predominate parallel, holistic, synthetic processing, and the LH predominates sequential, temporal and analytic processing. When the two hemispheres are both functionally specific, the processing of Chinese characters requiring configural processing then is thought to be RH specialised. On the other hand, the recognition of Chinese words requiring sequential analysis of the critical character orders is thought to be LH specialised.

Secondly, the differential lexical lateralisation hypothesis, claimed by Cheng and Yang (1989), concerned the morphological property of word stimuli. While a word always represents complete meanings, its constituent characters may not. As discussed in the characteristics of characters, some characters cannot be used as a morpheme (they are sublexical level units) and need to accompany others to make a word. The LH may favour words to characters due to the words' direct access to the lexical processing in the LH.

Thirdly, there is a differential perceptual degradation account, suggesting that stimuli with shorter exposure time are advantageously presented to the LVF rather than the RVF (Chiarello, 1985, 1988). Effectively, single characters needing shorter RTs should be favoured by the RH, and words containing two characters by the LH.

Lack of support for the Character-word dissociation

Fang (1997, 2003), among others, examined this controversial character-word dissociation with carefully controlled Chinese stimuli. However, Fang reported that both high-frequency words and characters show a RVF advantage, which is analogous to the processing of English stimuli. Additionally, she showed that the number of morphemes contained in a word does not actually affect the response latency of the two hemifields (Fang, 1997, Exp2). The number of morphemes was not effective in three-character monomorphemic, trimorphemic or phrasal stimuli (Fang, 2003). In a word, there are grounds for rejecting the view that the LVF advantage is a signature of the processing of the words of an ideographic language.

Tan, Spinks, Gao, Liu, Perfetti et al. (2000) challenged this character-word dissociation with brain imaging techniques and three types of word stimuli: single character words with accurate meanings, single characters with vague meanings, and two-character words. The results showed that LH activation occurred for all the stimuli. More specifically, the single characters with vague meanings and the two-character words had larger activation than single characters with accurate meanings. This finding has been interpreted that precise characters with well-defined meanings might be easily retrieved out of context. In contrast, the former two types of stimuli, single characters with vague meanings and 2-character words, need to trigger extensive activation of semantics or working memory, given the activation of the frontal areas. Furthermore, the occipital and parietal areas in the RH were also activated during the task, compared with the control condition. It was suggested that these areas might involve visual and spatial processing of characters and words, and that the RH did contribute to Chinese character/word recognition to some extent. Yet, the character-word dissociation was not replicated by research with brain imaging.

In summary, the character-word dissociation was a special finding in Chinese language processing concerning morphology; however, it has not been consistently replicated by other behavioural studies or by brain imaging research. Given that the English length effect occurred with increase in the number of letters but not with the number of syllables (Young & Ellis, 1985) or the number of morphemes (Batt, Underwood and Bryden, 1995), and that the number of Chinese morphemes was not effective to length effect (Fang, 1997, 2003), we manipulated Chinese word length in the present thesis by varying the number of characters contained in words. When studying single Chinese characters, we then control the complexity by fixing the number of radicals contained in characters, given that the radical is the basic orthographic unit, and that the phonology and semantics were reported to be activated at this level through a decompositional process.

1.4.4. Lateralised syntactic processing

Syntax is best processed by the LH, given that patients who have acquired damage in Broca's area often present with agrammatism, one of the classical syndromes of aphasia. As previously discussed, agrammatism is characterized by patients' good auditory comprehension ability, but their speech production is non-fluent, and they may omit function words (see, e.g., Packard, 1990). Paragrammatic speech may be fluently produced by aphasic patients who have impairments in auditory comprehension ability (Packard, 1990). These two syndromes typically result from impairments in the LH. Both syndromes constitute a syntactic inability, pointing to the importance of the LH in syntactic processing.

Lateralised syntactic processing in Chinese

Studies of brain imaging have shown that the brain areas activated in Chinese reading are not significantly distinct from those activated in English reading. Hoosain (1992) also reported that different languages or even different dialects do not occupy different processing loci within the brain. Thus, it is suggested that, generally, Chinese and English share similar brain regions for the language processing. Wong (2003) carried out an experiment to examine the neural correlates of syntactic and semantic processing of Chinese at the sentence level. She employed a syntactic task and a meaning judgement task, in which participants were asked to judge whether the presented sentence was syntactically or semantically acceptable. The syntax condition showed activation in the left middle frontal gyrus, consistent with the findings of Luke et al. (2002). As for meaning processing, activations were right lateralised with significant activations in the right middle frontal area. The results suggested that the left middle frontal gyrus is used for processing syntax information in Chinese, whereas semantic processing at sentence level is right lateralised. In brain impairment studies, there are several case-studies of crossed-aphasia in Chinese speakers (April & Tse, 1977; April & Han, 1980). The studies reported that lesions in the right frontal lobe or the right middle cerebral artery elicit crossed-aphasia in Chinese. From these cases of Chinese-English bilingual patients, April et al. found a greater functional dysfunction in speech occurring in Chinese than in English. April et al. suggested that the early learning/experience of a non-alphabetic and ideographic language is critical for the establishment and maintenance of language dominance in the RH, due to a greater demand of intensive functional collaboration of the RH and the LH for achieving the processing of the visual spatial features of the ideographs, compared with English. Therefore, the RH impairment might damage more language processing in Chinese (Chee et al., 1999; Tan et al., 2001a, 2001b).

1.5. Motivations regarding the three themes in this thesis

1.5.1. Theme 1: Lateralisation and the word-length effect

In general, the LH is thought to be typically dominant in word recognition, and this hemispheric dominance has been one of the essential issues in language processing. Predominantly in English, studies have shown a hemispheric lateralisation of the word-length effect, in that the RH is sensitive to the physical length of words whereas the LH is not. That is, when words get longer, each additional letter increases reaction time by approximately 20ms in the LVF. The declining performance of word recognition in the LVF together with the steady performance in the RVF represents a RVF advantage.

In 1985, Young and Ellis used a naming task to examine the RVF superiority for English words of different lengths to retest the claimed imageability-by-visual-field interaction. They found that males showed a significant RVF advantage for long, concrete nouns (Experiment 1). Secondly, the LVF performance declined markedly with increases in word length, whereas RVF performance remained unaffected. This interaction of word length by visual field was not observed for pronounceable nonwords, or for words with unaligned letters or with vertically aligned letters (Experiment 1, 2, 3). Finally, the length effect was significant in both concrete and abstract words, but was clearer in the later (Experiment 5). In 1987, Young and Ellis further noted that the length and visual field interaction depended specifically on visual length, not on phonological length as represented by the number of syllables in the word.

The RVF superiorities

Is it always true that the RH is more sensitive to the visual length of words than the LH? Studies using other paradigms have shed further light on the issue. In 1992 Reuter-Lorenz and Baynes instructed participants to recall a correct four-letter string from two alternatives: one of them was identical to the prime string and the other differed from the prime string by only one letter. Their results showed that for the trials presented in the RVF, the latter a wrong letter was located in the word, the more errors participants made, whereas there was no effect in LVF trials. That is, the LH was seemingly more affected by word length (possibly by virtue of the involvement of phonological, or at least sequential, processing). However, in another experiment of Reuter-Lorenz and Baynes (1992), participants were asked to make lexical decisions concerning three-, four-, five-, and six-letter words. Results showed a length effect on LVF trials, and no significant difference on RVF trials. Only the RH was influenced by word length.

These studies suggest that on the one hand, a hemisphere does not always necessarily perform the task for which it is thought to be superior. Hemispheric dominance may be more dependent on the mode of response. If a task concerns naming or lexical decision, the LH is expected to be superior and the RH should show increasing inferiority as the task becomes more difficult. On the other hand, in Reuter-Lorenz and Baynes' experiment the RH may have been less affected due to its typical dominance in the visuo-spatial abilities required by the visual matching task. Bouma (1973) suggested that the result is an outcome of lateral interference between letters; this lateral interference may have a greater spatial extent in the RH (Bub & Lewine, 1988).

Further to the established research in English, it is intriguing to connect the length effect and hemispheric lateralisation with Chinese. As Chinese comprise both graphemic information and linguistic characteristics in characters, will the hemispheric lateralisation be counterbalanced in the function of the visuo-spatial features?

Initial letter acuity and perceptual degradation

One factor that has been discussed in connection with why the word-length effects typically occur in the LVF but not in the RVF for a horizontal word is "initial letter acuity" (Anstis, 1974; Melville, 1957). Differences between the two halves of the brain may come from perception rather than from hemispheric asymmetry. Melville claimed that the initial letter of a long word in the LVF is further from the fixation point and hence less easily identified, compared with a word in the RVF (Ellis, Young, & Anderson, 1988). Young and Ellis discussed this hypothesis and reported that they found the word-length by visual field interaction even when the initial letters of short and long words were at a constant distance from fixation. Furthermore, Young and Ellis (1987) reported that the errors in the LVF words mostly involved the final letters, whereas the errors in the RVF words mostly involved the middle letters, rather than the high-acuity initial letter. Hellige et al. (1995) used an error-classification analysis of a task that involved the presentation of CVC words displayed vertically to the participant, either in the LVF or the RVF (see also Levy, Heller, Banich, & Burton, 1983) and reported that participants failed to identify the last letter far more often than the first letter on LVF trials. On the RVF trials, the mistakes were equal in the three positions and the difference between the errors was non-significant. As Hellige and Michimata (1989) comments, it is possible that the RH processes words and pseudowords in a relatively slow sequential, letter-by-letter fashion (see also Eng & Hellige, 1994). He suggested that the RH (connected to the LVF) is more likely to be seen a serial processor, whereas the LH is seen as a parallel processor. Fang (2003) has observed the initial character advantage of Chinese words presented in the LVF rather than in the RVF. Function-specific lateralisation seemed to occur in the case of Chinese orthography.

There is a claim that initial letter acuity interacts with perceptual degradation. The information contour of English is higher in the beginning of words and lower in the later parts; and visual acuity drops steeply away from the fixation location (Anstis, 1974). Degrading perception together with the asymmetric information contour therefore favours processing in the RVF. However, this factor of information profile within words was challenged by Bryden et al. (1990) for the failure to show a visual field difference in a task requiring judgements based on the last letters of words.

Young and Ellis (1985) noted that graphemic short-term storage may be involved in visual word recognition and may precede the recognition process for the LVF stimuli for abnormally formatted words and for nonwords. In contrast, normally formatted words presented in the RVF have rapid, parallel access to an internal lexicon. This interpretation explains why the RVF words are recognized more stably than words under any other conditions. Also argued by Seymour and MacGregor (1984) and Ellis (2004), if items are spatially distorted by vertical presentation or by other format distortion including case alteration, parallel access from letter forms to the visual input lexicon might be disrupted.

The LH then does not employ top-down processing at the word level. As reported by Ellis et al. (Ellis, 2004; Lavidor & Ellis, 2002 a & b; Lavidor, Ellis, & Pansky, 2002), the processing of words presented at fixation is affected by the number of letters to the left of fixation but not by the number of letters to the right and by the number of orthographic neighbours activated by letters to the left of fixation but not by the number of orthographic neighbours activated by letters to the right of fixation. Ellis and Lavidor suggested that the RH tends to be more sensitive and easily affected by virtue of word length and neighbourhood effects; it might be that the RH is simply less proficient in processing lexical stimuli, thus giving rise to the lateralisation.

What if a language can be vertically written and not spatially distorted? As vertical orientation is one of the normal directions in writing Chinese, we are interested to investigate the asymmetry of word-length effect in Chinese words.

Among recent studies regarding an Extended Optimal Viewing Position model (EOVP) (Brysbaert, Vitu, & Schroyens, 1996; Brysbaert & Vitu, 1998; Drieghe, Brysbaert, Desmet, & Debaecke, 2004), Brysbaert et al. provided a plausible explanation for the right visual field advantage. According to the EOVP model, the probability of a word being recognised is a function of word length and word position relative to fixation location. Brysbaert et al. argued that, for each presentation duration, the probability of recognizing a word at a certain distance could be described reasonably well with a Gaussian distribution that had the mode shifted slightly to the left of the word centre. With this optimal point in the left, the Gaussian curve declines more sharply in the left-half and gradually in the right-half. This extended, steady curve in the right half suggests a steady change in the recognition of words presented in the RVF parafovea, compared to the more sensitive and radical changes in the LVF parafovea. We will present a similar model by Shillcock, Ellison and Monaghan (2000) in Experiment 1 for the investigation of the information profile in words.

Regarding the issue of orientation, Whitney (2001) has proposed a computational model, SERIOL (sequential encoding regulated by inputs to oscillations within letter units) and predicted there to be no hemispheric lateralisation of the word-length effect in vertically written languages. In Whitney's study, she described the position of a word as being encoded by (a) its acuity gradient at the retinal level, (b) the effects of hemisphere-specific excitation at the feature level, (c) the effects of hemisphere-specific leftward lateralisation inhibition, and (d) hemisphere-specific locational gradients. The Acuity gradient and the locational gradients are in agreement with the perceptual degradation as previously discussed (*c.f.* Anstis, 1974, Brysbeart, 1996).

Whitney (2001) noted, for languages that are read from top to bottom, there should be no hemispheric asymmetry, since acuity gradient inversion in these cases should occur along the vertical axis not the horizontal axis. She quoted Hellige and Yamauchi (1999) that Japanese *kana* did not show a difference between the LVF and RVF presentation.

Kana and *kanji* are two writing systems of Japanese. As previously introduced, the *kana* system, like an alphabetic language, contains symbols representing the sound of a syllable without any meaning. *Kanji*, written like Chinese characters, is a meaning-based system. Observations have shown that *kana* and *kanji* represent different modes of linguistic processing because Japanese aphasic patients who have exhibited selective impairment of *kana* processing can at the same time remain able to process *kanji* (Hatta, 1977). The processing of *kanji* is more complex compared with *kana* because both visual and phonological information are likely to take part in the processing, similar to the processing of single Chinese characters. Thus it is hard to claim which hemisphere typically dominates processing, independent of the orthography used.

In fact, Whitney's theory was against the function-specific lateralisation supported by Hellige (1985) and many other studies in the field, such as Coney (1998) where a RVF advantage was observed with all Chinese word stimuli containing one, two and three characters in a vertical orientation. We suggest that Whitney's model was a theoretical information-based framework, which did not take account of the information profile of individual Chinese characters, such as that embedded in phonetic and semantic radicals and the inevitable phonological and semantic mediation/decomposition during the processing of Chinese. Additionally, as shown previously Japanese *kana* was more likely to be regarded as a phonological language which is critically different from ideographic writings such as Japanese *kanji* or Chinese.

Further, we are interested in the question of how the informational structure of two radically different languages would interact and assert themselves in the bilinguals, when their brains are assumed to be configured by their first language. We will examine the lateralisation of the word-length effect with Chinese characters and examine the intriguing bilingual issue with people having two language backgrounds – Chinese (L1) and English (L2) – and discuss these issues as Theme 1.

1.5.2. Theme 2: Bilateral effects and complexity

Functional lateralisation, and the coordination of information between the cerebral hemispheres, implies the possibility of the independent contribution of the two halves of the brain. However, one might ask: What keeps the two separate hemispheres acting in an apparently unitary way during everyday activities? How is interhemispheric integration achieved? Is it simply a matter of ensuring that the two hemispheres have the same amount of information, or does it involve a more complex system of inhibition or suppression of activity in the hemispheres? Furthermore, if a task requires functions coordinated by both hemispheres, will bilateral presentation be superior to unilateral presentation, causing a Bilateral effect?

Task complexity

The claim that interhemispheric interaction is correlated with task complexity has emerged from Japanese studies. Yoshizaki and Yayoi (2000) found a bilateral advantage in a task of judging name identity but a unilateral advantage in a task of judging physical identity. Yoshizaki and Yayoi suggested that the increases in computational complexity in the encoding stage would benefit from bilateral hemispheric processing. This result matches the results of Zhang and Feng (1998, 1999) in which the Bilateral effect occurred only when the complexity of the task was high.

Gestalt perception

The Bilateral effect may be conceptualised in other ways. One is the similarity principle of Gestalt perception. In Gestalt perception (Koffka, 1935), repeated objects have strong effects according to three Gestalt principles: Similarity, Proximity (or Contiguity), and Continuity (examples are presented in Chapter 5). The principle of similarity states that items which share visual characteristics such as shape, size, colour, texture, value or orientation will be seen as belonging together; the principle of proximity or contiguity states that things which are closer together will be seen as belonging together; the principle of continuity predicts the preference for continuous figures. Repeated items are usually seen as a unit or as having some connection, such as being part of the same object, or as having a common fate: there is a striking effect when identical objects are presented simultaneously. Bear in mind that this Gestalt type of perception has been seen as relatively peripheral, mainly involving visual perception. It was more described in a perceptual way rather than a cognitive way related to words and characters.

Redundancy gain

Mohr and Pulvermüller (2002) introduced the notion 'redundancy gain' to represent the advantage of simultaneous presentations of two identical realwords. They investigated the effect at the word level by presenting English words (two realwords or two pseudowords) with SOA 0 ms (simultaneously) and other specific SOAs from 50 to 300 ms for a lexical decision. Mohr and Pulvermüller reported that the simultaneous presentation of two identical words facilitates word recognition leading to higher accuracy and shorter response latency in lexical decision. Furthermore, not only the stimuli with SOA 0 ms showed facilitation, stimuli which were presented with SOA 150 and 180 ms also accelerated lexical decision. The 'redundancy gain', *i.e.* the facilitation of SOA 0 ms, was explained as a result from the double activation of sensory cortices as neuronal summation devices; whereas the second acceleration was explained as 'ignition priming', by which the cortical representation of the first stimulus was reached by the onset of the second stimulus. This interpretation was based on a Hebbian cell-assembly framework (Pulvermüller, 1999).

The notion of redundancy gain in a sense continues the psychological interest in the phenomena described under gestalt perception. This study is highly relevant to our interest in the Bilateral advantage and Chinese characters and words.

Hemispheric lateralisation and the Split fovea hypothesis

Another hypothesis to explain the Bilateral effect was based on the split fovea hypothesis. As argued by Shillcock et al. (2000, see details in Chapter 2), there is an optimal split point in words which, overall, allows readers' eye fixation to be understood in informational terms. The amount of information to the left of the mid point is higher than that in the right, so the splitting point tending to be in the left may evenly divide the amount of information, so as to equalise the information amount going to the two hemispheres. When vertical Chinese words are presented unilaterally or bilaterally, different amounts of information from the left and right part of characters/words will be projected to each hemisphere, even when the eyes shift to one of the two loci in the bilateral presentation condition. The details of how the fovea-splitting behaviour might affect the Bilateral effect will be presented with a graphic model in the chapter on the Bilateral effect, section 5.1.5.

The complexity and serial processing of vertically presented Chinese characters

We test the Bilateral effect with increasing word-lengths of Chinese words as the second theme starting from Chapter 5. We hypothesized that the Bilateral effect should occur in Chinese due to the highly complex nature of its orthography. We are interested to know how gestalt perception and redundancy gain operate in the double presentation of Chinese characters. When words are presented vertically, such as vertical Chinese words, the straightforward foveal-splitting may become more interesting, as Chinese may involve serial processing of characters, and long words comprising five characters might take more than 1000 ms for a lexical decision. In these cases, how will the priming effect occur in the recognition process? Mohr and Pulvermüller (2002) did not test the redundancy gain of two words simultaneously presented at the fixation point. This test will be carried out with Chinese characters at different spatial scales (one embedded inside the other) in the Chapter 6. Information in parafoveal vision is critical in bilateral Chinese character recognition; this issue will be investigated in Chapter 7.

1.5.3. Theme 3: Configural processing

Studies concerning the possible functional differences between the two hemispheres have shown that the LH typically deals with speech and language and with small-grain details, whereas the RH tends to deal with larger targets and may be thought of in terms of larger receptive fields. This processing preference can be explained by an information-coding model that is potentially related to anatomical processes: coarse encoding and conjunctive encoding (Beeman et al., 1994). In coarse encoding each elementary processing unit is broadly tuned so that properties or features specified by a unit tend to overlap in varying degrees with those specified by others. A visually presented item is represented by activity in a group of units within whose overlapping representational boundaries it falls. A coarse coding system tends to break down when it has to encode large numbers of highly similar, continuous events, like speech sounds, although it should be noted that it is perfectly possible for a coarse-coded system to make fine-grain distinctions, by trading on small overlaps between receptive fields. The RH anatomy is presumed to be dominated by the sort of overlapping horizontal connectivity at some level of description, typically represented as large, overlapping receptive fields, and is thought to be better at representing greater distances, and spatially and temporally disparate features, and to be weaker or less precise than the style of processing typically carried out by the LH.

In contrast, conjunctive encoding (or fine-grain coding) is seen as using a separate processing unit to stand for every aspect and every important relationship (conjunction) between items. Many of the materials considered to be in the realm of the LH such as language, require a memory system capable of highly specific, very compactly organized representations, in line with the characteristics of "vertical" columnar organization.

Figure 8 shows one typical representation of the two proposed styles of neuronal processing, giving the impression of a clear distinction between the LH and the RH. It should be noted that the actual anatomical structure of the human cerebral hemispheres does not clearly seem to match any such proposed schema

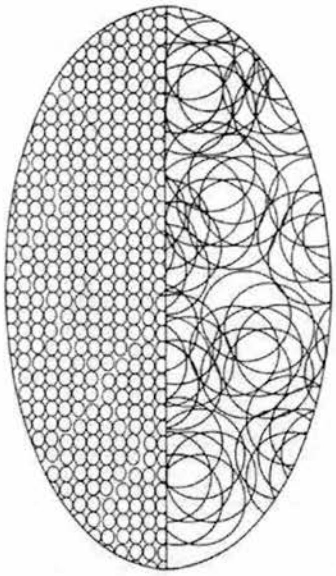


Figure 8. Two types of neuronal connection circuits (reprinted from Springer & Deutsch, 1989).

concerning different neuronal organization. There are observable anatomical differences between the two hemispheres, along such dimensions as amount of white matter, degree of dendritic branching, density of particular cell-types, and so on, but these differences are confined to particular regions of the brain, and in some cases may even be in the opposite direction to what was predicted by the coarse/fine distinction. Although the coarse-fine distinction is a compelling one at the functional level, at the level of processing preferences and observable behaviour, and has been a very productive distinction in terms of theory and modelling, it has proved hard to associate such functional differences unambiguously with observable anatomical differences. It may be that the two hemispheres differ in the way they typically adapt their processing strategies for particular tasks, instead of there being any simple coding difference, with directly observable anatomical implications.

N N

N N

NNNNN

N N

N N

Figure 9. A Navon figure: The letter H is made of the letter N.

Figure 10. An example of a coarse-coded word alone its "coastline".

The first example demonstrating coarse versus conjunctive processing is from LH lesions. When a letter "H" was formed out of "N"s, to produce a Navon figure as shown in Figure 9, a patient with a LH lesion would typically recognize it, first or only, as an "H", because of the patient's impaired ability in finding local features. In contrast, a patient with an RH lesion would typically recognize the component "N"s but be unaware of the larger scale organization. In the field of visual word recognition there have been longstanding claims for a role for coarser coding, so that the outline shape, for instance, might be used instead of analysing the word into its constituent letters (see Figure 10.) Thus, Allen, Wallace and Weber (1995) and Perea and Rosa (2002) proposed that the magnocellular pathways in the visual system carry out a check of the whole word in terms of its spatial frequency characteristics. Although there is magnocellular processing in each hemisphere, there have been persistent claims that it is the RH that specialises in low spatial frequency processing (see, e.g., Sergent, 1987). In general, any behavioural support for coarse-coding in visual word recognition has tended to come from less naturalistic reading tasks, such as proof-reading (see, e.g., Healy & Cunningham, 1992). When more standard psycholinguistic tasks, such as simple visual lexical decision, have been used the results have tended to be negative (see, e.g., Besner, 1989). (See Pelli et al. (2003) for studies suggesting that even the most frequent words are still represented in terms of their constituent letters.)

Face recognition and the Thatcher illusion

Several studies have demonstrated that participants typically recognize faces presented in the LVF more quickly than those presented in the RVF. The LVF advantage reveals the superiority of the RH in face recognition. Clinically, prosopagnosia, an inability to recognize familiar faces, is characterized in terms of bilateral damage in the parietal-occipital regions or in terms of unilateral damage in the posterior RH. A patient will not be able to recognize a previously known person's face and, in some cases, have difficulty recognizing his or her own face in a mirror. Some researchers have claimed that facial recognition involves some global or holistic analyses as opposed to feature-by-feature processing (Coin & Tiberghien, 1997). However, the study of the Thatcher Illusion (Thompson, 1980) has suggested that making the task of face recognition more difficult (in this case, by inverting the face) can force participants into using feature-by-feature processing, recognizing the separate facial regions independently. Thompson presented an inverted portrait of Margaret Thatcher with non-inverted mouth and eyes (Figure 11). The portrait is recognizable and does not seem unusual in the inverted version, but is grotesque when seen upright. The unawareness of the altered mouth and eyes in the inverted face makes the Thatcher Illusion. The experiment indicates that when a face is inverted and the features remain the same but the relative distances

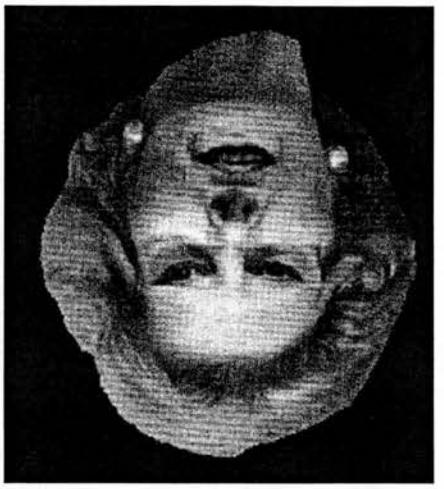


Figure 11. The inverted portrait of Margaret Thatcher, a "normal looking" picture.

between parts of the nose, eyes and mouth are changed, then face recognition is still accomplished independently in terms of its features.

A further example of separate pathways concerns Chinese character recognition. The ideographic kind of Chinese characters are made from pictures of objects, and so the recognition of these characters is arguably more like a holistic processing of the whole image (Hinojosa et al., 2000). Other kinds of Chinese characters, which are composed of more than one radical, are more complex. Readers may require recognition of both global format and fine-grain featural information about semantic and phonetic radicals to obtain the meaning and the pronunciation of a character. In the third theme we adapt the Thatcher illusion to inspect the two possibly separate processes in the recognition of Chinese characters. To control the complexity of single Chinese characters, the studies in this thesis used exclusively 4-portion characters, which were made up of four separate stroke patterns, rather than characters of a specific number of strokes.

1.6. Outstanding questions and the corresponding chapters

Having reviewed the features of the Chinese writing system, the normal reading of Chinese, the roles of the two hemispheres in language processing, and studies in the literature concerning English word recognition and Chinese character recognition, we describe experimental investigations designed to provide answers to the following questions. How does hemispheric lateralisation operate with regard to the increasing word-length of Chinese words (Chapter 2)? What is the distribution of information of Chinese multiple character words, and what are the implications for hemispheric processing (Chapter 3)? How do a native language and a second language interact in bilinguals: specifically, how does the information structure of the second language assert itself (Chapter 4)? Does the Bilateral effect occur in complex Chinese character recognition as well as in English word recognition (Chapter 5)? Is the Bilateral effect essentially a hemispheric effect, or can other functionally separate processing systems (specifically concerning spatial scale) be identified (Chapter 6)? Can a gestalt pattern processing interpretation of the Bilateral effect generalize to a situation in which multiple, but unattended, versions of the stimulus are present in both hemifields (Chapter 7)? Can we demonstrate a trade-off in the processing of Chinese characters, between configural and componential processing (Chapter 8)?

Answers to these related questions will clarify our understanding of the ways in which the rich information, which is spatially distributed within the average Chinese characters, interacts with the reading processor.

Theme 1. Word-length effect

Chapter 2. Hemispheric Lateralisation of the Word-Length Effect in Chinese word recognition

Abstract

One of the functional hemispheric lateralisations reported by Young and Ellis (1985) was the Right Visual Field Advantage in the recognition of long English words. However, this advantage may not be robust throughout cross-cultural linguistic materials, according to similar studies carried out with Chinese words by Fang (1994 & 2003). As Fang failed to show a significant interaction between visual field and word length in Chinese words, this study aims to replicate Fang's experiment with a different set of Chinese characters. We review studies showing the unstable tendency of hemispheric lateralisation in Chinese character/word recognition. We describe an experiment demonstrating the word-length effect in both of the visual fields. We interpret/hypothesize that Chinese orthography differs from English in terms of a more symmetrical information structure in Chinese multiple character words, which will be further tested in the next chapter.

(Part of this chapter has been published as Chou & Shillcock (2001a&b).)

2.1. Background

Previous studies have discovered various hemispheric lateralisations in English word recognition, such as word-length (Ellis & Young, 1985), concrete and abstract words (e.g., Ellis & Shepherd, 1974) and a word/number difference (e.g., Besner et al., 1982). The principle finding of a RVF superiority has been repeatedly reported for physically long English words. This is, increasing word length impairs RH performance whilst the LH performance remains steady, effectively resulting in the LH (RVF) superiority.

The Chinese writing system is distinctive from the English writing system, in that it has both pictorial and linguistic characteristics. These characteristics make the study of Chinese interesting because the LH is supposed to show a RVF advantage in word recognition tasks, compared with the RH which is typically dominant in processing pictorial images. The findings of hemispheric lateralisation are unstable in Chinese. Some studies suggest a RVF advantage whilst others claim an LVF advantage for similar tasks.

Table 1 shows a survey of studies concerning lateralisation of Chinese character/word recognition. Some of them were concerning the recognition of single Chinese characters, some used single Japanese *kanji* characters, and others used single characters and complex words that were comprised of multiple Chinese characters. Tasks in these experiments are mainly lexical decision and word identification. The results of the experiments overall do not show a consistent hemispheric lateralisation, as the LVF and the RVF advantage were each equally reported by half of the experiments each. It was claimed by Tzeng (1979) that the recognition of single Chinese characters generally had an LVF advantage whereas Chinese words had a RVF advantage. However, no support was provided by subsequent experiments.

Table 1. Related studies concerning Chinese word recognition.

Studies	Stimuli	Tasks	Results Error rate (ER) and Reaction time (RT)
Tzeng et al. (1979)	Single Chinese characters		One experiment had an LVF advantage.
Huang & Jones (1980)	Single Chinese characters		ER: One experiment had an LVF advantage. RT: On the other hand, no visual fields difference in response latency.
Besner et al. (1982), Nguy et al. (1980) & Tsao (1992).	Single Chinese characters		3 experiments had a RVF advantages
Cheng & Yang (1989)	Single Chinese characters		Characters with simple strokes yielded no significant visual field effect. On the other hand, characters with large number of strokes yielded an LVF advantage.
Fang (1994, Exp.3)	Single Chinese character composed of 2- and 4-portions.	Mixed tasks of with a lexical decision and stimulus identification.	RT: No significance.
Zhou & Marslen-Wilson (1999b)	Single Chinese characters	Naming task.	Chinese character recognition involves an automatic decomposition of radicals from complex characters. Both phonological and semantic primes can facilitate or delay the naming task of complex characters.
Hatta (1977a, 1977b, 1978)	Single Japanese Kanji		3 experiments had an LVF advantage,
Elman et al. (1981)	Single Japanese Kanji		1 experiment had no visual field difference for concrete nouns but a RVF advantage for abstract nouns.
Keung & Hoosain (1989)	2-character words, 12 to 21 ms exposure time and low luminance (21.6 cd/mxm)		RT: LVF advantage for low frequency words with high stroke numbers.
Fang (1994, Exp. 1)	2-, 3-, 4- and 5-character words, low frequency, vertically oriented.	Mixed tasks of a lexical decision and stimulus identification.	ER: No significance for visual field or their interaction. RT: Significant length effect: 2- and 3-character words were recognised faster than 4- and 5-character words. No significant VF effect or interaction.
Fang (1994, Exp. 2)	2- and 4-character words, high frequency, vertically oriented.	Mixed tasks of with a lexical decision and stimulus identification.	ER: No significance for length effect or their interaction. RT: Significant RVF advantage, but no length effect or significant interaction.
Zhou et al. (1999a)	1- and 2-character words	Lexical decision and naming task.	Semantic priming effect is significant and is stronger than homophone (phonological) priming in the word recognition; the later is significant in naming task.
Fang (1997)	2-c word with one or two morphemes		No morpheme effect
Fang (2003) exp 1, 2	All vertical, 2-, 3-, and 5-c words.	Sementic decision task: whether a name is geographicl or biographical. Target detection (TD) task: whether a name has been dysplayed before or not.	Length effect. No Visual Field by length interaction. LVF initial character advantage > RVF.
Fang (2003) exp 3, 4	3-c words with one or three morphemes	Lexical decision TD	No morpheme effect. Bilateral effect in accuracy, not in RT. Initial character advantage.
Fang (2003) exp 5, 6	1-, 2- and 3-character phrases	Completeness judgement TD	Length effect. Initial character advantage.

One means of resolving the inconsistencies is by taking account of the way in which foveal splitting interacts with the distribution of information within the character. (We discuss the issue of foveal splitting at greater length at the end of this chapter, and elsewhere in the thesis.) For fixations distributed around the midpoint of the character, the left part of the character will tend to be projected initially to the RH, and the right part to the LH. This initial splitting will have important implications to the extent that there tend to be qualitatively different types of information in the two halves of a character (as in the phonetic-complex characters), and to the extent that the processing of a character tends to involve decomposition. If this is the case, then the two hemispheres will tend to be doing different tasks, collaborating in the processing of the whole character. This situation is in contrast to explanations of the word length effect in English, in which it is assumed that each hemisphere is effectively processing the same type of information, but doing it in a different manner, and leading to one hemisphere carrying out the processing more effectively.

Two studies conducted by Zhou et al. (1999 a, b) aimed to investigate the decomposition procedure in Chinese character/word recognition. In Zhou's experiment, he introduced a priming effect with a radical that was phonologically or semantically similar to a target character. He hypothesized that if the prime significantly improved or delayed the recognition latency of the target character, it indicated the relevant phonological or semantic processing. The results supported his hypothesis and showed that the recognition of characters/words involves a decomposition procedure when a character/word is briefly presented for a naming task or lexical decision. Specifically the phonological prime affected the naming tasks. These experiments reflected the complex and dense information contained in single Chinese characters.

The current chapter concerns the word-length effect and hemispheric lateralisation in word recognition. In 1994, Fang first conducted experiments with Chinese words but failed to find a significant interaction between Visual Field and Word Length. She found either a significant Word-Length effect or a Visual Field effect individually in separate experiments. This failure to find an interaction between length and visual field is important given the robustness of the effect in English. In the following sections we report a replication of Fang's experiment with a more elaborate set of Chinese word stimuli and a different presentation regime.

2.2. Experiment 1. Length effect of Chinese characters

2.2.1. Hypothesis

Fang's study in 1994 and 2003 showed no hemispheric lateralisation in Chinese character recognition by the absence of a significant interaction between word length and visual field. However, this outcome might result from the limited range of Chinese stimuli that Fang used, or from the limitation of the presentation to 250 msec. The current experiment used a new set of Chinese words that were different from Fang's, together with longer inspection time, and hypothesized a length effect in Chinese character recognition.

2.2.2. Participants

In this experiment, participants were able to read Chinese in traditional fonts. We used traditional font because its radicals and components retain more intact pictorial and semantic information from ancient times, compared with the recent simplified font. Twenty-three Taiwanese students studying in the University of Edinburgh participated in this study. Their average age was twenty-nine for twelve males and twenty-seven for eleven females. All of them were native Mandarin speakers and skilled Chinese readers with normal or fully corrected vision. All participants were right-handed according to *The Edinburgh*

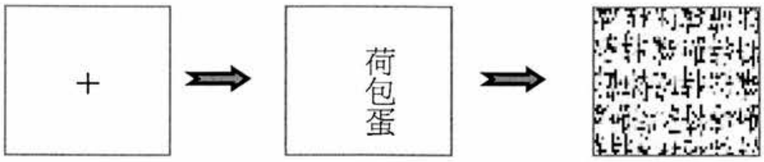


Figure 12. The sequence of unilateral presentation.

Handedness Inventory (Oldfield, 1971) and self-report. The judgement of handedness was based on questions in the Inventory, such as which hand was used for writing, holding chopsticks and badminton rackets, plus self report of whether there were any family members who were ambidextrous or left-handed. People with more right hand tendencies on the questionnaire were judged as right handed. Those who were right-handed and none of their family were ambidextrous or left-handed were judged as strongly right-handed. All the participants in this experiment fit the criterion of strongly right-handed.

2.2.3. Design

Stimuli were 120 vertically displayed Chinese words and non words consisting of 2, 3 and 5 Chinese characters, which were chosen from *the most frequent nouns in Journal Chinese and their classification: Corpus-based research series* (1993, by the Chinese knowledge information processing group). Each of the three length categories contained 20 nonwords and 20 real words. This was a within-participant design. Half of the words were presented in the LVF and the other half the RVF. The participants were divided into two groups randomly. The presentation condition and stimuli were arranged by a Latin Square design; therefore the words used in the first participant group were identical to those in second one, except that the stimuli presented in the LVF for the first group were presented in the RVF for the second group.

Nonwords were made by switching two characters within a real word. For example, a three-character word like 荷包蛋 (he2 bao1 dan4) was changed to 荷蛋包 (he2 dan4 bao1). The fixation point was a 4 mm × 4 mm cross (Font: Bodoni MT Ultra Bold. Size: 24. Duration 1000 msec) presented at the centre of the monitor to draw participants' attention. A masking pattern was produced by overlapping randomly dozens of Chinese strokes and characters that did not appear in the formal experiment. In addition, there were fifteen practice trials preceding the experiment.

All of the Chinese materials were produced by PhotoShop and presented by Psyscope Version 1.2b5 (1994) and a Macintosh computer. The size of each character was 13 mm × 13 mm and the inter-character space was 9 mm, thus the three different lengths of words were 13 mm × 35 mm, 13 mm × 57 mm and 13 mm × 100 mm respectively. All the stimuli were presented on the screen either 2 mm to the right hand side of the fixation point or 2 mm to the left hand side of the fixation point. The smallest visual angle was equivalent to 0.25 degree from the fixation point, as presented in Figure 12.

2.2.4. Procedure

Participants faced the centre of the monitor at a distance of 450 mm to 550 mm from their eyes to the monitor, and pressed the right or left response button with the right or left index finger to make a lexical decision. For all the participants, pressing the right button with the right index finger was for realwords and pressing the left button with the left index finger was for nonwords. The experimenter explained the instructions and observed participants' responses for fifteen practice trials, and then participants were left alone whilst doing the formal testing. The Psyscope software recorded response latencies with millisecond precision.

The sequence of presentation was, first, a fixation point, presented centrally for 1000 msec, followed by a unilaterally presented vertical Chinese stimulus which was ended by the critical response or which ended automatically after 2000 msec, followed by a masking picture presented for 1000 msec, as shown in Figure 12.

2.3. Analysis and results

An analysis of variance of response latencies was carried out both by participants and by items. In the by-participants analysis, both Visual Field and Word Length were within-participant factors, whereas in the by-items analysis, Visual Field was a within-item factor and Word Length was a between-item factor. Any data which were 2 standard deviation above or below the mean were replaced with the average number for that participant. The following Tables 2 to 5 and Figure 13 show the mean response latencies.

A significant main effect was found for Word Length (F_1 (2, 44) = 273.81, $p<$ .001 .1; F_2(2, 114) = 91.79, $p<$ .001), but not for Visual Field (F_1 (1, 22) = .47, $p>$ .1; F_2(1, 114) = .24, $p>$ .1). As shown in Tables 3 and 4. The two-way interaction between Word Length and Visual Field was non-significant (F_1 (2, 44) = . 30, $p>$ .1; F_2(2, 114) = .35, $p>$ .1).

Table 5 shows the post hoc test for the Length variable. The three levels of word lengths are significantly different from each other. In summary, word-length effect was significant with longer words producing longer response latencies than shorter words. Although the stimuli presented in the LVF were responded slightly slower than those presented in the RVF, the main effect of Visual Field did not reach significance, neither by participants nor by items. Nor was there any significant interaction between Word Length and Visual Field. We conclude that hemispheric superiority for word length, as found in English, does not appear to exist in Chinese, from the results of this experiment.

Table 2. Descriptive statistics of the word-length effect.

Visual Field	LENGTH	Mean	Std. Error
RVF	2-character words	782.18	33.99
	3-character words	862.91	29.55
	5-character words	1156.76	42.20
	Total	933.95	32.95
LVF	2-character words	776.87	24.96
	3-character words	881.83	34.79
	5-character words	1167.44	34.40
	Total	942.04	28.71
Total	2-character words	779.52	27.69
	3-character words	872.36	30.76
	5-character words	1162.10	36.58

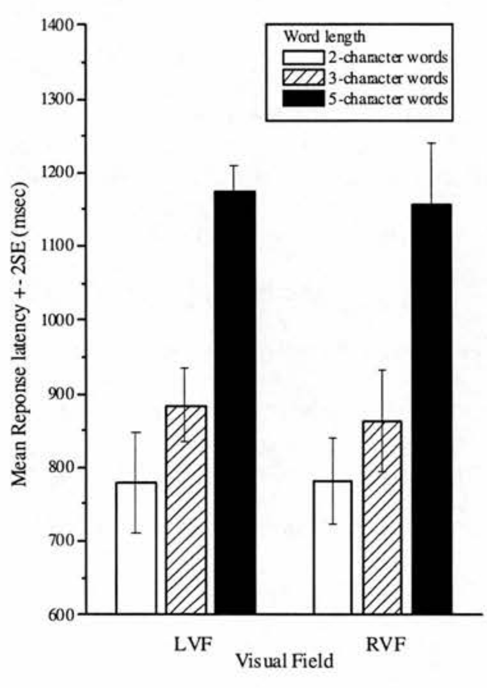


Figure 13. Overall by-participant results in the word-length effect

Table 3. By-participant analysis: tests of Within-Subjects Effects.

Source	Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	
VF	2260.54	1.00	2260.54	.47	.50	
Error(VF)	106329.62	22.00	4833.16			
LENGTH	3663551.67	2.00	1831775.83	273.81	.00	**
Error(LENGTH)	294354.38	44.00	6689.87			
VF x LENGTH	3490.63	2.00	1745.31	.30	.75	
Error(Visual Field x LENGTH)	259434.37	44.00	5896.24			

Table 4. By-item analysis: tests of Between-Subjects Effects

Source	*df*	*F*	Significant.	
Visual Field	1.00	0.24	0.62	
LENGTHS	2.00	91.79	0.00	**
VF x LENGTHS	2.00	0.35	0.70	
Error	114.00			

Table 5. Multiple Comparisons (Scheffë test)

Dependent Variable: Reaction Time (msec)			
(I) Word length	(J) Word length	Mean Difference (I-J)	Sig.
2.00	3.00	94.88	0.01**
	5.00	389.87	0.00**
3.00	2.00	94.88	0.01**
	5.00	294.99	0.00**
5.00	2.00	389.87	0.00**
	3.00	294.99	0.00**
* The mean difference is significant at the .05 level			
** The mean difference is significant at the .01 level			

2.4. Discussion and Conclusion

This experiment replicated the methodology of Fang (1994). We extended her research by using a different set of stimuli and adding word stimuli comprising five characters. The results showed a significant main effect of Word Length; neither the main effect of Visual Field nor the interaction between Visual Field and Word Length reached the significance level.

2.4.1. Size of word lengths

Studies in the literature have shown that only the long words of English could elicit hemispheric superiority, and short words could not (Young & Ellis, 1985: the RVF superiority in recognition of long English words). It might have been the case that the Chinese materials failed to show a significant lateralisation being due to: the word lengths 2 to 5 characters being too short to allow the lateralisation to emerge. This claim can be dismissed given three essential features of Chinese: First, there was an indisputable length effect found in both hemispheres in the present study. If the length were not long enough, the length effect should not have occurred at all. Secondly, a slight lateralisation was shown in three-character words though the significance did not reach the .05 level. Thus, words longer than 3 characters should accordingly belong to the long word group and show a hemispheric advantage if the lateralisation were strong enough to be consistently found in Chinese. Thirdly, five-character words are almost ranked as the longest words in Chinese because words containing more than five characters are very rare. Due to the constraint of usage frequency, we can hardly use any words longer than 5 characters. Hence, in short, the stimuli we used in the present study were two-character words, three-character words, which are the most common word lengths in Chinese, and five-character words, the longest words frequently used in modern Chinese, and yet no length by visual field interaction occurred.

2.4.2. Length of exposure time

The present experiment used long exposure time for stimulus presentation and it might be argued that the exposure time may be one of the factors eliminating the visual field differences, given that (a) it allows refixation of the stimulus to occur, thereby allowing the transfer of information and collaboration of the two hemispheres and resulting in equivalent performance of two hemispheres. The exposure time in this experiment was designed to be 1000msec: longer than that for English word recognition. The average response latencies in our study was 779.52msec for two-character words, 872.36msec for three-character words and 1162.10msec for five-character words. The more complex a word is, the longer time it needs for lexical decision, just like recognizing the English word "postillion" takes more time than the word "post". Most Chinese characters comprise both semantic and phonetic radicals, and they took longer time for recognition and for a lexical decision. Secondly, the exposure period we used in this experiment does not need to be critical because the information in the LVF was still initially going through the RH, and the information in the RVF was initially through the LH. Finally, Fang (1994 and 2003) presented words with durations below 250msec and failed to find the visual field by length interaction. A short inspection time clearly does not guarantee that a length by visual field interaction might emerge.

2.4.3. Vertical orientation

Character by character processing

Since the principal difference between the present study and the English experiments was the vertical presentation of words, it might be argued that the vertical orientation we used may have played a role in the lateralisation. One of the reasons that we presented materials vertically was to avoid the initial letter acuity issue raised since 1988. Bub and Lewine (1988) have argued that the

LVF		RVF
D		D
A	+	A
G		G

Figure 14. Experiment presentation of Hellige (1995).

lateralisation found in horizontal English recognition was because that the initial part of the words presented in the RVF was closer to the former fixation point, compared with the words presented in the LVF. The initial letter was more informative than other letters, so that the closer the initial letter was to the fixation point, the quicker was the recognition. Chinese is the ideal language to be used in comparable studies, because vertical presentation is one of the normal orientations of Chinese writings, compared with the exclusively horizontal presentation found in English experiments. By this vertical orientation, we could keep the distance equivalent from the central fixation cross to the materials in both visual fields.

The claim that the absence of lateralisation is the result of the vertical orientation of Chinese stimuli can be argued from the position taken by Hellige et al. (*cf.* Eng & Hellige, 1994; Hellige, Taylor, & Eng, 1989; Hellige, 1995) (see Figure 14). Hellige et al. hypothesized that if the lateralisation of word recognition is a function of an anatomical difference between the two halves of the brain, the writing orientation should not stop us finding the effects of lateralisation. He supported this view by reporting that the lateralisation also occurred in vertically written English materials. Figure 14 presents Hellige's experiment. In the LVF, errors were reported in G, fewer errors in A, and fewest errors in D. However, in the RVF, the errors were equal in the three positions. The accuracy was asymmetric in the two halves of the brain even if the orientation was vertical.

Hellige's study is explained by the function-specific asymmetry: the hemispheric asymmetry may result from the fact that the RH (initially viewing the LVF) is seen as a serial processor, whereas the LH is seen as a parallel and analytic processor. Thus the words presented in the RVF might be processed in parallel and holistically by the LH, causing more evenly spread errors in recognition. On the other hand, in the case of Chinese processing, given the fact that Chinese characters and words are highly complex, especially those comprising multiple characters, recognition is more likely to be processed in a character-by-character paradigm (cf. Osaka (1993): the recognition of vertically presented characters was not influenced by the visibility of neighbouring (upper or lower) characters for Japanese *kanji* characters). Hence, the RH/LVF advantage should have occurred because of the superior sequential processing. In summary, the vertical presentation results for English CVC words support that a length by visual field interaction could have been visible in Chinese as a result of a function-specific asymmetry.

As reported by Lavidor et al. (Lavidor & Ellis, 2002a & b; Lavidor et al., 2002), the interaction of word-length and visual field found for words with upper and lower case letters was not observed for words with mixed cases. Case alteration made the word forms more complex and disrupted normal lexical processing, although the length effect was still significant in both visual fields. This result for English raises the issue of visual complexity.

2.4.5. The complexity of Chinese words

We consider that the phonological information embedded in Chinese characters should be taken into account in assessing the general tendency towards a RVF advantage in language processing. First of all, English studies show a RVF advantage for recognizing long English words, possibly because the LH was dominant in dealing with acoustic stimuli and phonological information (Schwartz & Tallal, 1980; Studdert-Kennedy & Shankweiler, 1970). Together with the advantageous position of phonological radicals typically appearing on the right of the character, phonological radicals will tend to be initially projected to the LH and to benefit from the processing preferences of the LH. However, Chinese words and characters are highly spatially complex and contain richer spatial, figural information than alphabetic orthography, hence the LH's superiority is phonological processing may be offset by the RH's superiority in spatial processing.

2.4.6. The information contour

Shillcock et al. (2000) used entropy, an information measure, together with the split fovea model to explain the lateralisation shown in English. Entropy is defined as the expected amount of information necessary to describe a system; expected amount is further defined as the amount of information which is actually an average covering the various possible states of the system. Take Figure 15 for example, Shillcock et al. reported that, when words are all left-justified as those in Figure 16, all the letters c are located in the first position of words and we have c at the first position three times. Thus in Figure 16, we mark letter c as 3. Given a letter c in the first position makes it rather difficult to anticipate what the word might be after c in this case. Effectively, the type frequency of the letter in a particular position represents how informative it will be for guessing the word. A small number of times for a particular letter in the same position make a position more informative. In other words, the larger the variation of letters in a particular position, the more informative the position (i.e. the higher the entropy at this position).

| cast

| chair

| cloud

Figure 15. Left-justified words.

Letter	a	b	c	d.....
Frequency	**0**	**0**	**3**	**0.....**

Figure 16. The number of letters in the first position of words.

ca | sk

cha | ir

d | esk

Figure 17. An example of allocation of three words.

Following this rationale, Shillcock et al. (2000) designed a programme to find the ideal fixation point of each word in a lexicon of English such that there would be minimal confusion between the left halves of all of the words and between the right halves of all of the words. The arrangement of allocation is exemplified in Figure 17, where three words, *cask*, *chair* and *desk* could be split by any inter-letter space. If the first split occurs in the centre of the word "cask", then the letters "ca" will be allocated to the left and "sk" to the right. Secondly, now that we have the letter "sk" in the right side, we should avoid the repetition of the letters "sk" to the same position. Meeting this principle, the word "desk" is not to be split from the centre, rather, in Figure 17, it was split into "d" and "esk", and the word "chair" was split as "cha" and

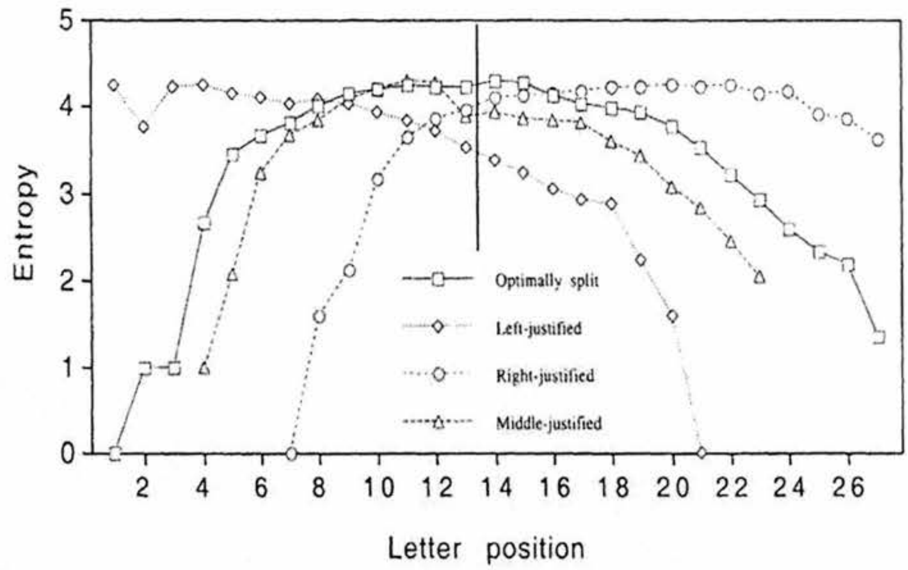


Figure 18. The asymmetrically distributed information (reprinted from Shillcock, et al., 2000).

"ir". Then the programme carried on with the rest of the English lexicon.

Shillcock et al. ran the orthography several times in order to find the optimal results of different splits. The overall results of the splitting program (presented as Figure 18) show that the information is asymmetrically distributed either side of the splitting points, through which words are initially divided and hence, the information is transferred and processed through two visual fields (Shillcock, et al., 2000). The curve of optimal splitting has the highest entropy falling on the left of the central point of words. Furthermore, the entropy drops dramatically in the left hand side, and is flatter in the right hand side.

English is written from left to right and the optimal fixation point of English word recognition is to the left of the mid point, rather than the mid point itself. This optimal viewing position curve matches Brysbaert et al. (1996), as discussed in the Introduction. The entropy shows that the amount of information in the left of the mid point of words is richer than that in the right, so the splitting point tending to the left may evenly divide the amount of information to equalise the information amount going to the two hemispheres (*cf.* Brysbaert, et al. 1996; Whitney, 2001).

When words are presented vertically, as what we did with Chinese characters in this experiment, such horizontal splitting can not occur. We claim that the lack of LH advantage was due to the lack of sufficient experience in reading left-to-right words. Chinese readers are exposed to vertical text for a large proportion of the time and the LH has insufficient experience of horizontally orientated words being fixated to the left of centre for recognition efficiency and insufficient experiences to learn to process longer parts of words better than the RH.

In addition, the optimal viewing position is not found in Chinese reading (Wang et al., 1999): the fixation points are almost equivalently scattered between- and within-characters, thus the hemispheres may process the whole word on the basis of their perceptual learning and the LH is not more used to longer parts of words than the RH. As a result, the RVF advantage is not as large as was found in English orthography.

In a Japanese study by Kajii, Nazir and Osaka (2001), there was an OVP fixation landing on the initial character of Japanese script, when the script was mixed by *kanji, kana* and *gana* (the third type of Japanese writing) and all the spaces between characters were removed. The OVP occurred more at the word beginning with a *kanji* character. However, the result was confounded with the visual distinctiveness of the three types of characters.

It is important to note that there is no demonstrated OVP fixation behaviour in Chinese reading; however, there might still be hemispheric effects of the distribution of information in Chinese words. This assumption is supported by Fang (2003) where an initial character advantage over the final character was observed in words comprising one to four characters. In the next chapter we will carry out a statistical analysis to inspect the information contour of Chinese multiple character words and compare the varieties of the first halves and second halves of words split from the mid point.

In summary, this study has inspected the processing of complex Chinese words unilaterally presented in both visual fields and shown a significant word-length effect in both presentation conditions. Crucially, the hemispheric asymmetry found in the recognition of English long words was not replicated in the recognition of Chinese words. The information contour of Chinese words, the complexity and the fine-grain information processing in Chinese single characters may have played important roles in the elimination of the RVF advantage. These factors will be tested respectively in Chapters 3, 5 and 8. The next chapter will examine two possible hypotheses to explore the informational structure of Chinese multiple character words.

Chapter 3. The Information Contour of Chinese Multiple Character Words

Abstract

The information structure in English words is asymmetric, with more information in the initial letters of the words and less in the later parts. From the perspective of the split fovea model, words are initially divided between the hemispheres when they are fixated, and it is adaptive for each hemisphere to obtain equal amount of information, resulting in behavioural lateralisations. In this chapter we inspect Chinese multiple characters statistically, aiming to test the Flat *versus* Asymmetric Information Contour Hypothesis in the two halves of Chinese words which are spilt from the central point. We show that Chinese two-character words tend to show a symmetric information structure, while four-character words tend to show an asymmetric information structure. This result falsifies the flat information contour hypothesis. We suggest that the absence of hemispheric lateralisation may be attributed to the complexity and dense information both at the word level and at the single character level.

3.1. Background

Given that the amount of information in the two halves of a word is typically not equivalent, the brain/reader has the option of projecting more or less information to each hemisphere, by virtue of where in the word the fixation falls.

Figure 18 in Chapter 1 shows the statistical study by Shillcock et al. (2000) of reading behaviour, fixation points, and also the optimal viewing position (OVP) in English word recognition. The OVP behaviour had two consequences of interest for this research. First, the OVP falls to the left of the mid-point in order to tend to obtain equal entropy in the distribution of segments at particular positions in the two parts of the word. The amount of information is richer in the initial or the left half, of English words. Therefore this left-tending OVP simply splits the words to be unequal in length but equally informative in the two hemifields/hemispheres. Secondly, these unequal physical lengths, caused by OVP splitting, tend to cause longer parts of words in the RVF to be projected to the left half of the brain, and shorter parts of words in the LVF to be projected to the right half of the brain, and results in a different experience (and different perceptual learning) for the LH and for the RH. The LH typically has to deal with longer parts of words.

Even within the foveal window the amount of obtained information drops from the middle point to the outside. (The fovea needs to focus on words to obtain accurate information; the window onto a word is limited by the perceptual span about 6 English letters. Or four character spaces to the left of fixation and 14 to the right (McConkie & Rayner, 1976). Underwood and McConkie (1985) further demonstrated that letters are distinguished only within eight character positions to the right.) As shown in Figure 18, the curve of entropy at each letter position falls sharply on the left side and slowly on the right. This reveals that the longer right part of fixated words is projected to the LH. Thus physical length affects the LH less. On the other hand, the RH is used to dealing with shorter parts of words. As a consequence, in the comparison of recognition of a long word in the RVF with that in the LVF, the RVF shows a significant superiority. The conclusion is that the OVP splits the words to be physically unequal and results in different experience (perceptual learning) for the two hemispheres, and then gives rise to the hemispheric lateralisation of the word-length effect in English word recognition. If Chinese words have a similar information gradient higher in the left and lower in the right half of words, that would be the nearest analogue to English.

The OVP phenomenon in English refers to lexical decision behaviour for isolated words in which initial fixation position is manipulated to the left or right. In text reading, the analogous behaviour is referred to as the Preferred Viewing Location (PVL), which is the tendency to fixate words even further to the left of the OVP.

However, there is no reported PVL-like behaviour in the reading of Chinese text, according to Sun (1993). The studies most relevant to OVP and PVL behaviour in Chinese were Liu (1983), Yang and McConkie (1999) Tsai and McConkie (2003). Liu showed that in the recognition of Chinese single characters, the upper half of a character is more essential and informative than the lower half (see *Introduction* for details). Note that the experimental paradigm in this case was rather cruder than that used in the OVP paradigm; parts of the character were simply lost. Liu showed that there was no left-right differentiation like English word recognition. We are not aware of any OVP study in Chinese more comparable to the English ones. The second study was a PVL technique by Yang and McConkie and showed that the recognition of two-character Chinese words was not as sensitive to fixation location as was the recognition of words from alphabetic languages. Chinese readers' eye fixations

微 笑

1 2 3 4 5

Figure 19. Eye fixations of a two-character word.

fall equally onto the characters themselves and into the inter-character spaces. As shown in Figure 19, a two-character word like 微笑 (wei2-xiao4, 'smile') attracts eye fixations falling equally on inter-character spaces 1, 3 and 5 and intra-character spaces 2 and 4. This lack of PVL-like behaviour could be partly because there might be no information gradient in Chinese words. Perhaps Chinese characters are equally informative when comprised in words, and perhaps splitting is not therefore motivated by an information gradient in Chinese, hence there is no differential perceptual learning of word lengths in the two hemispheres. This could explain why the RVF superiority in Chinese character recognition is not as significant as in English. This hypothesis, the flat information contour hypothesis (FICH), is what the current chapter tests: Chinese multi-character words will have a flat information contour, with the implications for the lateralization of the word-length effect that we have discussed. The alternative hypothesis is the asymmetric information contour hypothesis (AICH). If the FICH is falsified, then this outcome would lessen support for the interpretation we have advanced of the lateralization of the word-length effect.

The calculation of the information profile of Chinese words, which we describe below, resembles at least three different kinds of calculation in an alphabetic language like English. The first is the calculation of orthographic neighbours (Coltheart, 1978): the number of words that differ from the target

座　座

＋

椅　椅

Figure 20. Vertical presentation of word stimuli.

word by just one letter. The second is the calculation of entropy within each letter position: thus entropy is higher towards the starts of words in English. The third is the calculation of morphological productivity: larger morphological families (e.g. workman, workplace, worker, workforce, working, workable ...) facilitate visual lexical decision (see, e.g. del Prado Martin, 2003). How words vary on these dimensions has demonstrable processing consequences in alphabetic languages like English, and these processing consequences are beginning to be explored in hemifield terms. For instance, Lavidor and Ellis (2002a & 2002b) reported that in English there are neighbourhood effects in the right hemisphere but not in the left hemisphere: word recognition in the LVF is more sensitive to the number of orthographic neighbours (N) than recognition in the RVF. The other important point is that, Lavidor and Ellis have found N effects for centrally presented words that reflect the number of neighbours defined by letters occurring to the left of fixation, not the number of letters occurring to the right of fixation.

An additional reason to carry out this study involves the initial letter acuity issue. As addressed in the discussion in Experiment 1, a vertical presentation of Chinese materials keeps equal distance from the central fixation point to the initial points of words in the two visual fields. (as shown in Figure 20) in order to avoid confounding initial letter acuity with the word-length effect. This issue was argued by Bub and Lewine (1988) to be an explanation of the RVF superiority in recognition of long English words reported by Young and Ellis

Chair + Chair

Figure 21. An example of the Initial letter acuity.

(1985). Bub and Lewine speculated that the lateralisation found in horizontal English word recognition was due to the fact that the initial point of the words presented in the RVF was closer to the former fixation point, compared with the words presented in the LVF, as shown in Figure 21.

Fang (2003) has shown an advantage of initial character over final character in target detection tasks. This finding was observed in two-, three-, and four-character words with a vertical orientation. Fang reported that there was a tendency toward an LVF advantage for this initial character effect. The tendency is consistent with the CVC strings in Hellige et al. (1989): the top letter was detected more accurately than the final letter, and the tendency was greater in the LVF.

We may speculate whether the information contour in Chinese words is akin to that in English words, that the most informative point lies within the first half of words. Are Chinese characters equally informative in their first and second halves or do they have a similar information structure as English? This study aims to answer this question.

3.2. Experiment 2. Variation in Chinese words

3.2.1. Hypothesis

From the flat information contour hypothesis (FICH), we assumed that the amount of information is equivalent in the first and second halves of Chinese words.

Example 1. 身體 body;

媒體 media

Example 2. 中產階級 middle class;

中小企業 small and middle enterprise

Figure 22. The example of the calculation.

3.2.2. Method

Two thousands sentences comprising two-character words were chosen from the *Sinica corpus* (1996, by Chinese knowledge information processing group). We first filtered out the repeated words; 651 different two-character words remained and were used in this corpus study. The same strategy was repeated for four-character words; 693 four-character words were used in the study. These words were divided equally at their mid-points. We restricted our analysis to two- and four-character words as they can be split equally in two, without making the additional assumptions necessary for three-character words. We then counted the variations in their first halves and second halves. Examples of the calculation are presented in Figure 22. In example 1, the first halves are 身(shan1) and 媒 (may2), respectively, so the variation is 2; two words share the same second character, 體 (ti3). In example 2, the first halves of four-character words are 中產(chung1-chan3) and 中小 (chung1-xiao3), respectively. Although they share the same first character 中 (chung1), 中產 (chung1-chan3) and 中小 (chung1-xiao3) are still calculated as two different kinds of first halves, so the variation is again 2.

3.3. Analysis and result

The results are presented in Table 6. For both word lengths, there was more variation in the first half than in the second half. The Binomial Test showed that

Table 6. The results of Binomial test.

	The number of different words	The varieties of the 1st half.	The varieties of the 2nd half.	The results of Binomial test.
2-character words	651	389	344	P = .104
4-character words	693	650	568	*P*< .05

the difference for the two-character words did not reach significance (p> .05), whilst the variations of the two halves of four-character words did reach significance (*p*< .05). On this basis, we can say that the variation in the first half tends to be greater than the variation in the second half of Chinese words, but the effect only reaches significance in longer words.

3.4. Discussion and conclusion

3.4.1. Flat information contour

The results falsified the flat information contour hypothesis and demonstrated that information in Chinese words is asymmetrically distributed, but significantly so only in longer words comprising 4 characters. This result contrasts with the more robust informational asymmetry in English. The effect is in the same direction in Chinese and in English, although the orthographic units, and the processing they elicit, are very different. We turn now to the processing implications.

If Chinese and English are similar (to the extent that we have shown), then a PVL effect should have occurred in Chinese word recognition during text reading, causing perceptual learning reflecting that information structure: *i.e.* we might expect Chinese words to be fixated more towards their left, analogous to English words. However, we know from Sun (1993) that Chinese does not have the PVL phenomenon, despite the information gradient that we know is there. As shown in Table 7 (reproduced from Yang & McConkie 1999), there appears

Table 7. The probability of initial fixation at different word locations in two-character words (Yang & McConkie, 1999).

	Space	Character		Space	Character	
Fixation location	0	1	2	3	4	5
Target words only (%)	17.7	16.9	18.0	17.4	15.8	14.2
All two-char. words (%)	17.7	16.4	17.3	16.5	15.6	15.3

to be no specific landing position when reading a Chinese two-character word. The probability of landing position is similar between or within characters. Thisbehaviour could result from the fact that single Chinese characters are more complex and comprise denser and richer information concerning not only phonology but also their meanings, compared with English words and letters. For this reason, character recognition proceeds predominantly in a character-by-character paradigm, and this limits the hemispheric asymmetry to be found in Chinese word recognition. The character-by-character phenomenon was supported by the study of Osaka (1993). The study demonstrated that the visibility of characters in the neighbourhood did not significantly affect word recognition for Japanese *kanji* characters. That is, when characters were vertically displayed, the results did not significantly differ when the upper and the lower sides of characters were masked (only the character fixated was present) or unmasked. However, there is also some support for parafoveal effects in horizontal reading of Chinese characters (Rayner, Inhoff, Morrison, Slowwiaczek, & Bertera, 1981). The perceptual span in Chinese reading is about one character to the left and two to the right of the fixation point (Inhoff & Liu, 1998). One possibility is that the Osaka and the Rayner et al. studies obtained different results because of the different orientation of the text.

Reduced parafoveal preview, and greater character-by-character processing may contribute towards the fact that there is apparently no PVL behaviour in reading Chinese text. In this explanation, it is the density of the Chinese text that is provoking different processing. But given that parafoveal preview does exist in reading Chinese words, a more compelling explanation of the absence of PVL behaviour might be found in the details of the statistical analysis we have presented.

A robust informational asymmetry has been found in English words, but we did not find such a clear asymmetry in Chinese words. Two-character words are the majority of words in any text, but the informational asymmetry was barely marginally significant (p = .104). There is thus only a weak pressure for the reader to position fixation at a left-displaced informational midpoint. Any such behaviour may be further weakened by the fact that the granularity of Chinese text is relatively coarse: positioning fixation just to the left of the centre of a two-character word (*i.e.* just left of the space between the characters) may introduce other complications by sending different parts of the fixated character to different hemispheres. A more robust informational asymmetry exists in longer words, as we have shown, but such words may be too scarce to have a significant effect on the reading of text.

The arguments we have advanced are the best explanation for the fact that there are informational similarities as well as a processing difference between English and Chinese, where a robust asymmetry in the length effect was not found in Chinese but was in English. We can still claim that the informational asymmetry is responsible for the asymmetrical length effect in English.

Finally, we can consider the reading of single characters. Figure 23 (reproduced from Sun, 1993) shows eye-movement patterns when a single character is inspected. 23A shows a Chinese character "ling2", meaning "soul". Figure 23B shows that the eye movements only made one fixation to recognize the character, when the character is well-known to the participants. 23C shows that the eye is scanning the components of the character, when the participant is

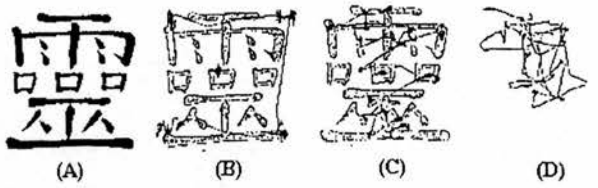


Figure 23. An example of eye movement patterns in character recognition.

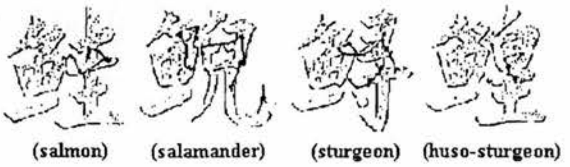


Figure 24. Eye-movement pattern of Chinese reader.

familiar with components only. 23D shows that the eye movement is more random when the participant is not a Chinese reader.

When the reader is familiar with the character, a single fixation may suffice for the recognition of the word. When a component of the character is less well known, that component may attract further fixations. Figure 24 shows that when a Chinese reader is familiar with the semantic radical "魚" meaning "fish", located on the left of the character, his/her eyes may tend to focus on the right of the character, seeking phonological information from a phonetic radical. We cannot fully interpret this behaviour as simply fixating a high-information part of the character, as opposed to allowing equally informative parts of the character to be projected to the two hemispheres. The existing literature does not seem to contain OVP studies comparable with those by O'Regan and Jacobs (1992), in which a single character is presented at different positions with respect to the initial fixation point. However, we are able to make testable predictions from the position we advance here. Within individual Chinese characters, the content of the left of the character is typically more predictable than the content of the right of the character; this conclusion is clear from lexicography (see, also, Hsiao & Shillcock, *in preparation*). There is therefore a clear prediction that, if there is any OVP-like behaviour in the reading of individual Chinese characters, the optimal viewing position will tend to be right of the centre of the character, often dividing the phonetic radical between the hemifields/hemispheres.

In summary, a PVL-like phenomenon has not clearly been shown in reading Chinese. This state of affairs might result from the following. (a) The fact that the majority of Chinese words comprising two characters have less of an asymmetric distribution of information than do English words. Longer words comprising four characters do show a significant asymmetric information contour but the processing effect they provoke is not sufficient to be visible in reading behaviour as a whole. (b) A single character containing a very unfamiliar component might cause a change in the domain over which processing momentarily occurs, so that attention moves to that unfamiliar component and any hemispheric division of labour only occurs with respect to that component, as opposed to the whole character. (In English words there are no such unfamiliar letters.) (c) Based on lexicography, we know that the phonetic radicals (numerically some 1499) are less predictable than the semantic radicals (numerically some 214). It may be that this typically rightward-skewed informational contour within each character eclipses the less extreme leftward-skewed information contour across the whole word. Rooted in this complexity, the OPV or PVL phenomena may not be found in Chinese as simply and consistently as in English.

It is important to note that Chinese has a special phonological neighbourhood effect resulting from the number of homophones a character possesses. As discussed in the Introduction, characters with more than one homophone show an interference effect in lexical decision and in an immediate naming task. The number of homophones a character possesses affects phonological mediation in Chinese character recognition (Ziegler et al., 2000). Homophones also produced a significant interference in a Stroop colour-naming task, provided that they had the same pronunciation or the same tone as the colour characters (Spinks et al., 2000). Furthermore, phonological activation at the radical level and character level are both essential for word naming. Radical-level activation (of phonetic radicals) is critical for naming low frequency characters because the pronunciations of these characters tend to be regular with their phonetic radicals; whereas character-level activation and contextual information are important for naming characters with more than one pronunciation. Various strategies involved in the recognition of Chinese characters due to their high complexity seem to play important roles and inevitably interact with each other and result in the weak hemispheric lateralisation in the processing of Chinese.

3.4.2. Conclusion

To sum up, in Experiment 1 we have found that the word-length effect in Chinese character recognition appeared in both visual fields equivalently. No interaction of hemifield by word-length was found. Furthermore, Experiment 2 demonstrated that the first halves of four-character Chinese long words were significantly more informative than the second halves, while the majority (the two-character words) tend to have a flat information contour. This result falsified the flat information contour hypothesis. Any hemispheric lateralisation that might have occurred in Chinese may be eliminated by the complexity and density of Chinese characters both at the word level and at the single character level. This issue will be inspected in Chapter 5. In the next chapter we continue to examine the role of the information structure in lexical processing by looking at the interaction between the information structure of English words and the hemispheric asymmetries in lexical processing, the pre-existing processing predispositions, present in the brain of Chinese native speakers.

Chapter 4. Bilingual Study of Hemispheric Lateralisation in the Recognition of English Words

Abstract

In this chapter we ask whether the informational structure of the English lexicon could assert itself by producing a RVF advantage in participants with Chinese as a native language. (N.B. These is no such clear advantage in Chinese.) An absence of such an advantage would clearly falsify our claim for the role of the informational structure of the lexicon, given in the previous chapters that the asymmetric informational structure in English partly results in the RVF advantage. In this chapter we repeated Mohr, Pulvermüller and Zaidel's (1994) study on the recognition of English function words and content words in the two hemifields. This study confirmed the tendency towards a RVF advantage in the recognition of function words in English monolinguals. We demonstrated a tendency towards a RVF advantage for English word recognition in Chinese-English bilinguals, and an overall significant advantage in the recognition of content words over function words. However, there was no Visual Field by Word type interaction. This result suggested that the left hemisphere might be advantageous in processing English syntax for English native speakers, whereas Chinese-English bilinguals may not have such an automatic mechanism in the LH. Critically, the demonstration of the tendency towards a RVF advantage for English words in Chinese-English bilinguals fails to falsify our claim concerning the role of the informational structure of the lexicon.

4.1. Background

We have seen that a coherent case can be made for a hemispheric division of labour in English visual word recognition, in line with the informational structure of the English lexicon. A number of phenomena, such as the word-length effect, can be interpreted in these terms. We have further seen, that the information structure of Chinese words and characters contrasts with that of English words: the entropy statistics we saw in Chapter 2 were more or less flat for words of two characters, and the information structure within individual characters is in the opposite direction to that found in English (*i.e.* there is more variation on the right side of Chinese characters than the left). In this chapter we address the question of what happens when the informational constraints present in English must express themselves in a brain that has been configured by the informational constraints of Chinese. Specifically, we will look at whether well-attested lateralised behaviours in English emerge in the reading behaviours of Chinese native speakers who are proficient readers of English.

According to Price and Devlin (2003), it is highly unlikely that a reading specific brain region would have developed in the human brain, such as the visual word form area (VWFA) in the middle portion of the left fusiform region, as claimed by Cohen, Lehericy, Chochon, Lemer, Rivard, and Dehaene (2002). Price and Devlin suggested that, on the one hand, the left midfusiform gyrus is active in many other tasks such as picture, colour and letter naming, and matching of auditory words or pseudowords, irrespective of lexicality. The left midfusiform region is clearly driven by visual input but it also responds to tactile and auditory stimuli that do not entail visual processes. Price and Devlin suggested this region is a polymodal area; it may be referred to as a 'convergence zone', where many neural loops make contact and interact as a set. On the other hand, visual word reading is highly complex and imposes great demands on unique interactions between visual and language regions which are in charge of many different functions. This processing also involves a grand configuration of orthographic, semantic and phonological processing developed from childhood to adulthood. For the current experiment, we hypothesized that this grand configuration that one develops in learning the first language is not going to change wholesale in relation to a different language. Learning to read a second language means that the relevant processing must accommodate itself to the anatomy of the brain and visual pathways, and also to any existing processing that might be co-opted to the new task. At its most abstract, the question is whether it is the informational profile of the second language that alone determines how the processing of that language develops in the brain, or does it do so in conjunction with the (first-) language that already exists in the brain?

Although PET studies have shown that there are common cortical areas activated by both L1 and L2 in bilinguals including Chinese-English, English-French, English-Italian, and Catalan-Spanish (*cf.* Klein, Milner, Zatorre, Zhao, & Nikelski, 1999), a cognitive task is able to show more detailed and qualitative differences between L1 and L2. In the current experiment, we will look at two of the most reliable instances of lateralization in the literature on English word recognition, and explore the same effects in the reading of English by Chinese native speakers. The two effects are the RVF advantage for word reading, and the RVF advantage for function words over content words. The two languages are radically different at many levels, so we will hypothesize that the effects of lateralization may mean that the information structure of English is a difficult task in imposing itself on processing that has been configured by the information structure of Chinese.

For English studies, there is a RVF advantage for reading words, and there is a RVF advantage for function words. The reasons for the RVF

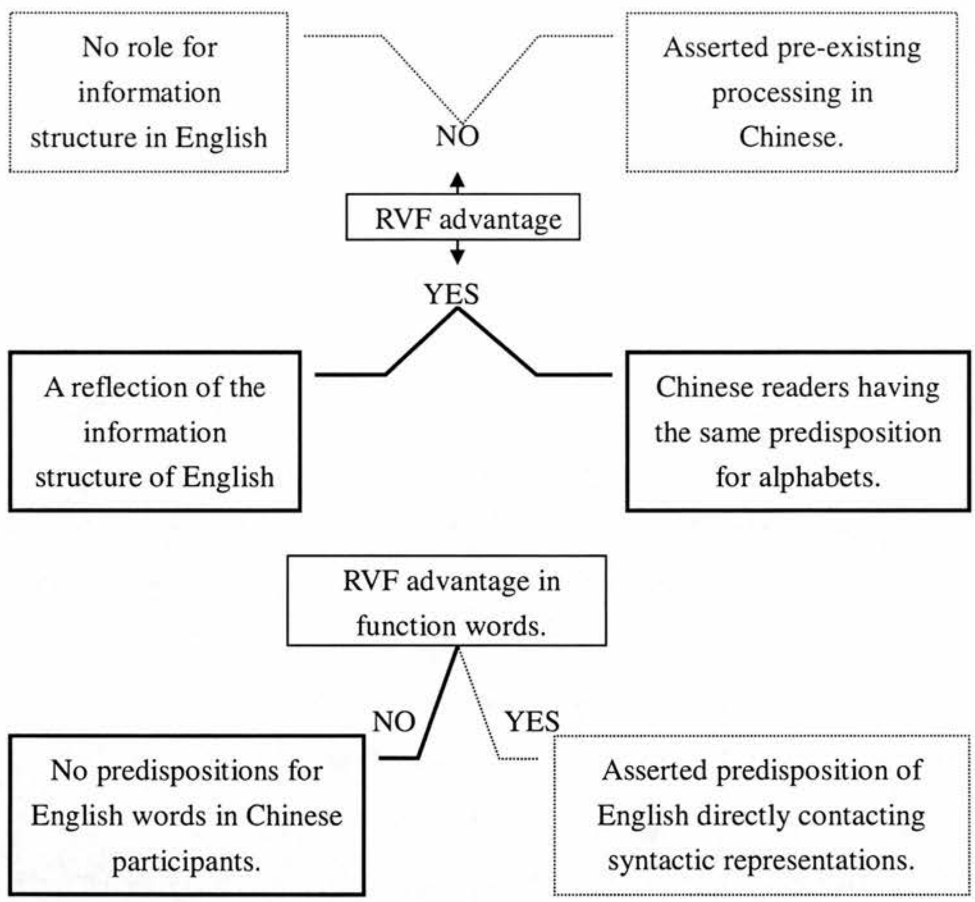


Figure 25. Hypotheses of the Bilingual study.

advantage in the reading of English words may be due to a combination of constraints from the anatomy of the brain and from the informational structure of the language (cf. Eviatar, 1995, 1997: for Hebrew and Arabic studies in which it appears that the right-to-left information structure of the Semitic languages does not wholly configure processing). The RVF advantage in the reading of English function words could reflect the direct access to syntactic processing in the LH (Zaidel, 1994).

If we find no RVF advantage when Chinese participants read English words, then we might infer that the information structure of the English orthography was not sufficiently salient to impose itself on the processing of the second-language learners. Instead, we might believe that the pre-existing processing relevant to Chinese has asserted itself, given that there is no clear overall RVF advantage for Chinese words, as we have seen. In contrast, if we find a RVF advantage for English words in the Chinese readers, then we can see this effect as a reflection of the information structure of English words and/or as the result of the Chinese readers having the same predisposition for alphabetic processing as native English speakers/readers. (Figure 25)

The task of reading function words gives us another insight into lateralisation. For native English readers there is a RVF advantage for function words, as we have seen. By testing for the presence of this same RVF advantage for English function words in Chinese readers, we are again looking at the issue of whether a predisposition on the part of the LH might assert itself. The general interpretation of the RVF advantage for function words in English readers is that these words are directly contacting syntactic representations in the LH, just as alphabetic words might be directly contacting phonological representations in the LH. If we find no RVF advantage for English function words in the Chinese readers, then we can infer that second-language reading between languages as different as Chinese and English does not readily make use of processing predispositions that are assumed to exist in first-language readers of English (and thus, the information structure of the second-language words may play a larger role).

The current experiment duplicates the methodology of Mohr et al. (1994), where they showed a RVF advantage in the recognition of English function words performed by English native speakers. Our study uses the same set of English stimuli (Mohr et al., 1994) and added a new variable, language, to examine the performance of two groups: English monolinguals and Chinese-English bilinguals (with Mandarin Chinese as the first language and English as the second). We hypothesise that we will find a RVF advantage in

English word recognition by the Chinese readers, thereby allowing us to exclude the strong claim that information structure of the lexicon plays no role at all. We hypothesise that we will find no RVF advantage for English function words in the Chinese readers, thereby allowing us to conclude that potential pre-existing predispositions of the hemispheres do not have sole sway over the ways in which patterns of processing are developed.

4.2. Experiment 3: Lateralisation in Chinese-English bilinguals

4.2.1. Participants

Chinese bilingual group was made up by ten male and eleven female bilinguals participated in this study. They are native in Mandarin Chinese and proficient in English. English group was made up by eleven male and ten female English native speakers from the University of Edinburgh. They are monolingual in English. All of the participants had normal or corrected vision. Handedness was assessed by *The Edinburgh Handedness Inventory (Oldfield, 1971)*, together with family history: if a right-handed person had no family member who was left-handed, he was grouped as strongly right-handed. Only strongly right-handed were included in the analysis.

4.2.2. Stimuli

Stimuli and methodology were taken from Mohr et al. (1994). We list all the stimuli we have used in the Appendix; they are 80 real-words and 80 non-words. The real-words consisted of 40 content words including concrete nouns, verbs and adjectives, and 40 function words including articles, pronouns, auxiliary verbs, complementizers, conjunctions and non-*ly* adverbs. Non-words were matched with real-words in frequency of occurrence of the real words they

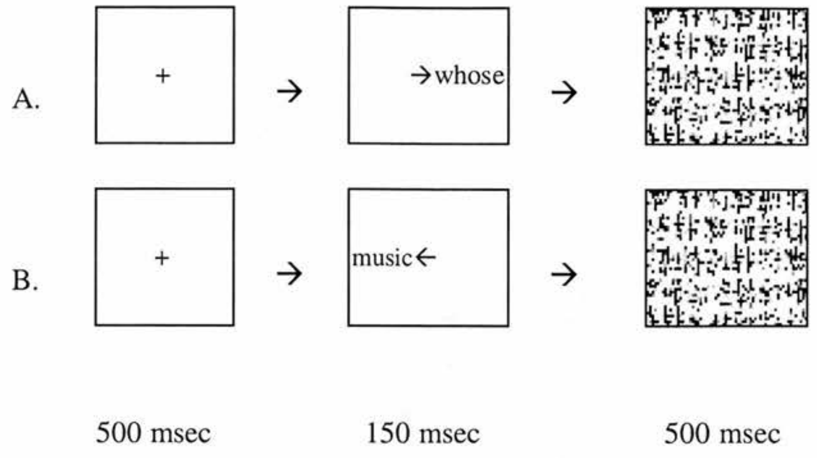


Figure 26. Presentation conditions in this experiment.

were constructed from, numbers of graphemes, phonemes, syllables and regularity of spelling. They were all pronounceable pseudowords, constructed either by permuting letters within one word or by exchanging some of the letters with letters of other words of the same category. They were orthographically regular and not homophonous to real-words.

4.2.3. Procedure

Experiment procedures were as shown in Figure 26. A fixation point was made by a cross (Font Courier, Size 14) and presented for 500 msec in the centre of the monitor, preceding the presentation of each stimulus word. The stimuli were in Courier font 14 point, and lasted for 2000 msec or were ended by a critical response. They were presented unilaterally and horizontally 35 mm right or left of the fixation point (the positions were Horizontal 416 to Centre, Align Left or Right, in Psyscope). Participants were instructed to fixate their eyes on the central point and make a lexical decision as soon as possible when the stimulus appeared. They were asked to place their index fingers on the keys F and J, and place the middle fingers on the keys of D and K. Half of the

Table 8. Descriptive Statistics of Bilingual study.

LANGUAGE	VF	WORD	Mean	Std. Error
English speakers	LVF	Content	605.02	22.76
		Function	627.66	25.06
	RVF	Content	605.18	22.12
		Function	606.02	22.06
Mandarin speakers	LVF	Content	664.15	18.09
		Function	692.40	19.92
	RVF	Content	655.21	17.58
		Function	683.39	17.53

participants were instructed to press both of their index fingers simultaneously for the real-words, and to press both of the middle fingers for the non-words. Another half of participants were to press both of their index fingers simultaneously for the non-words, and to press both of the middle fingers for the real-words. This design was to counter-balance the fingers used for making critical responses due to that the responses made by index fingers might be quicker than those made by middle fingers. Thus the instruction of fingers to use was assigned to participants randomly. There were rest periods every 60 trials during the progress of the experiment and 20 practice trials preceding the experiment.

4.3. Analysis and results

4.3.1. Overall descriptive statistics

Statistical analysis was carried out by items and by subjects. In the initial analysis the participants were pooled over the two language groups. The results are presented in Tables 8 to 18, Figures 27 and 28. Main effect of Language was significant in both by-subject and by-item analyses ($F_1(1, 29)= 4.96$, $p< .01$;

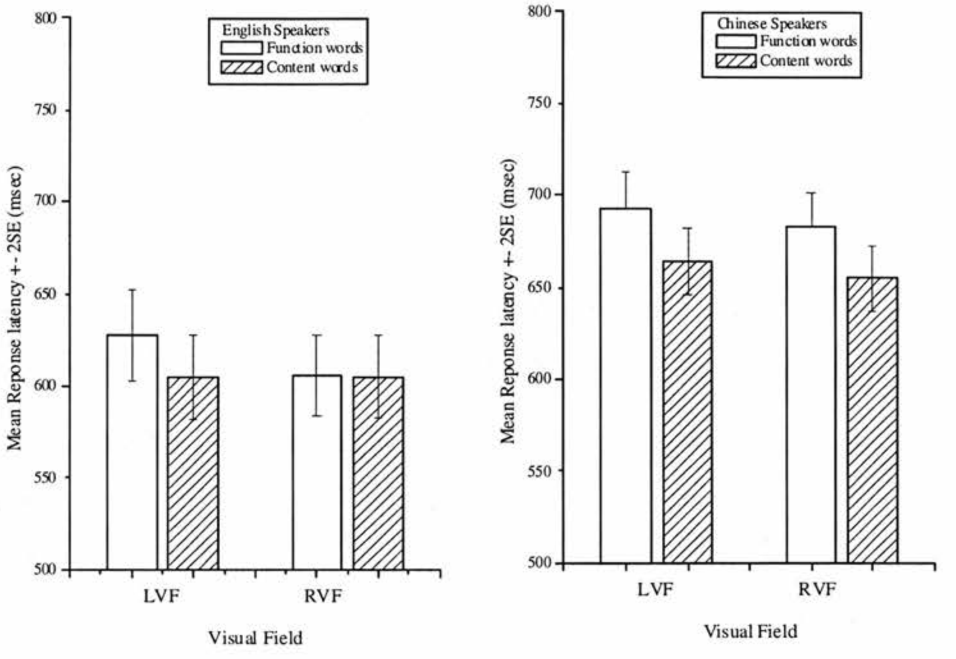


Figure 27. Overall results by Languages.

$F_2(1, 38) = 21.58$, $p < .01$) such that English speakers were faster in the task than Chinese speakers; and the Visual Field effect was significant in the by-participant analysis and marginally significant in the by-item analysis ($F_1(1, 29) = 5.05$, $p < .05$; $F_2(1, 38) = 3,15$, $.05 < p < .1$) such that there is a RVF advantage over the LVF. Word category effect was significant in by-participant test, such that content words were responded faster than function words. But this effect was non-significant in by-item test ($F_1(1, 29) = 13.38$, $p < .01$; $F_2(1, 38) = .13$, $p > .1$). However, none of the two-way or three-way interactions were significant: Visual field by Word category interaction ($F_1(1, 29) = 1.44$, $p > .1$; $F_2(1, 38) = .12$, $p > .1$); Word category by Language interaction (F_1 $(1, 29) = 2.27$, $p > .1$; $F_2(1, 38) = .44$, $p > .1$); and Visual field by Language interaction (F_1 $(1, 29) = .04$, $p > .1$; $F_2(1, 38) = .33$, $p > .1$).

Three-way interaction (F_1 (1, 29)= 1.42, p> .1; F_2(1, 38) = .10, p> .1). This experiment showed a significant RVF advantage for recognition of words, a significant content word advantage over function words, and a significant effect of the native language background.

4.3.2. Effects for English speakers

In the by-participant analysis, a Language effect was found to be significant (as presented in Tables 10 and 11). Participants with different first languages had different performances. Generally English speakers responded to the overall materials faster than Chinese bilinguals. In the English group (Tables 13 to 15), none of the main effects or the interactions was significant: the Visual Field effect (F_1 (1, 11) = 1.59, p> .1; F_2(1, 38) = .93, p> .1), Word category effect (F_1 (1, 11)= 2.87, p> .1; F_2(1, 38) = .09, p> .1), and their interaction (F_1 (1, 11)= 2.29, p> .1; F_2(1, 38) = .26, p> .1). Results, illustrated in Figure 27 and 28, showed a tendency for a RVF advantage in the recognition of function words, but this advantage was not found in content words (word difference in the LVF: F_1 (1, 11)= 5.8, p< .05; word difference in the RVF: F_1 (1, 11)= .01, p> .1).

4.3.3. Effects for Chinese speakers

For Chinese bilinguals (Tables 16 to 18), the Visual Field effect was marginally significant in the by-participant analysis but non-significant in the by-item analysis (F_1 (1, 18) = 4.03, .1 >p> .05; F_2(1, 38) = 2.58, p> .1); Word category was significant in the by-participant analysis but not in the by-item analysis (F_1 (1, 18) = 14.25, p< .01; F_2(1, 38) = .34, p> .1); and the two-way interaction was non-significant in either analysis (F_1 (1,18)= .00, p> .1; F_2(1, 38) < .01, p> .1).

Table 9. By-participant analysis, tests of Within-Subjects Effects.

Source	Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	
VF	2857.27	1.	2857.27	5.05	.03	*
VF x LANGUAGE	22.94	1.	22.94	.04	.84	
Error(VF)	16410.23	29	565.87			
WORD	11736.59	1	11736.59	13.38	.00	**
WORD x LANGUAGE	1996.21	1	1996.21	2.27	.14	
Error(WORD)	25446.29	29	877.46			
VF x WORD	879.51	1	879.51	1.44	.24	
VF x WORD x LANGUAGE	867.67	1	867.67	1.42	.24	
Error(Visual Field x WORD)	17711.62	29	610.74			

* The mean difference is significant at the .05 level

** The mean difference is significant at the .01 level

Table 10. By-participant analysis, tests of Between-Subjects Effects.

Source	Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	
LANGUAGE	116085.16	1	116085.16	4.96	.03	*
Error	679007.98	29	23414.07			

* The mean difference is significant at the .05 level

** The mean difference is significant at the .01 level

Table 11. By-item analysis, tests of Within-Item Effects.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	
LANGUAGE	73138.84	1	73138.84	21.58	.00	**
LANGUAGE x WORD	1496.89	1	1496.89	.44	.51	
Error(LANGUAGE)	128753.86	38	3388.26			
VF	5807.25	1	5807.25	3.15	.08	m
VF x WORD	227.07	1	227.07	.12	.72	
Error(VF)	69943.52	38	1840.61			
LANGUAGE x Visual Field	533.22	1	533.22	.33	.56	
LANGUAGE x VF x WORD	173.03	1	173.03	.10	.74	
Error(LANGUAGE x VF)	60173.80	38	1583.52			

m: marginally significant, .05 $<p<$ .1

* The mean difference is significant at the .05 level

** The mean difference is significant at the .01 level

Table 12. By-item analysis, tests of Between-item Effect.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
WORD	468.51	1.00	468.51	.13	.72
Error	137930.31	38.00	3629.75		

Table 13. By-participant analysis, tests of Within-Subjects Effects, English speakers.

Source	Type III Sum of Squares	*df*	Mean Square	*F*	Sig.
VF	1383.67	1.00	1383.67	1.59	.23
Error(VF)	9573.72	11.00	870.34		
WORD	1652.86	1.00	1652.86	2.87	.12
Error(WORD)	6339.61	11.00	576.33		
VF x WORD	1425.32	1.00	1425.32	2.29	.16
Error(Visual Field x WORD)	6837.14	11.00	621.56		

Table 14. By-Item analysis, tests of Within-Item Effects, English speakers.

Source	Type III Sum of Squares	*df*	Mean Square	*F*	Sig.
VF	1410.53	1.00	1410.53	.93	.34
VF x WORD	398.28	1.00	398.28	.26	.61
Error(VF)	57565.59	38.00	1514.88		

Table 15. By-Item analysis, tests of Between-Item Effects, English speakers.

Source	Type III Sum of Squares	*df*	Mean Square	*F*	Sig.
WORD	145.26	1.00	145.26	.09	.77
Error	64723.27	38.00	1703.24		

Table 16. By-participant analysis, tests of Within-Subjects Effects, Chinese speakers.

Source	Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	
VF	1529.46	1.00	1529.46	4.03	.06	m
Error(Visual Field)	6836.51	18.00	379.81			
WORD	15121.18	1.00	15121.18	14.25	.00	**
Error(WORD)	19106.68	18.00	1061.48			
Visual Field x WORD	.03	1.00	.03	.00	.99	
Error(Visual Field x WORD)	10874.49	18.00	604.14			

** The mean difference is significant at the .01 level

m: the effect is marginally significant.

Table 17. By-Item analysis, tests of Within-Item Effects, Chinese speakers.

Source	Type III Sum of Squares	*df*	Mean Square	*F*	Sig.
VF	4929.96	1.00	4929.96	2.58	.12
VF x WORD	1.83	1.00	1.83	.00	.98
Error(VF)	72551.74	38.00	1909.26		

Table 18. By-Item analysis, tests of Between-Item Effects, Chinese speakers.

Source	Type III Sum of Squares	*df*	Mean Square	*F*	Sig.
WORD	1820.14	1.00	1820.14	.34	.56
Error	201960.91	38.00	5314.76		

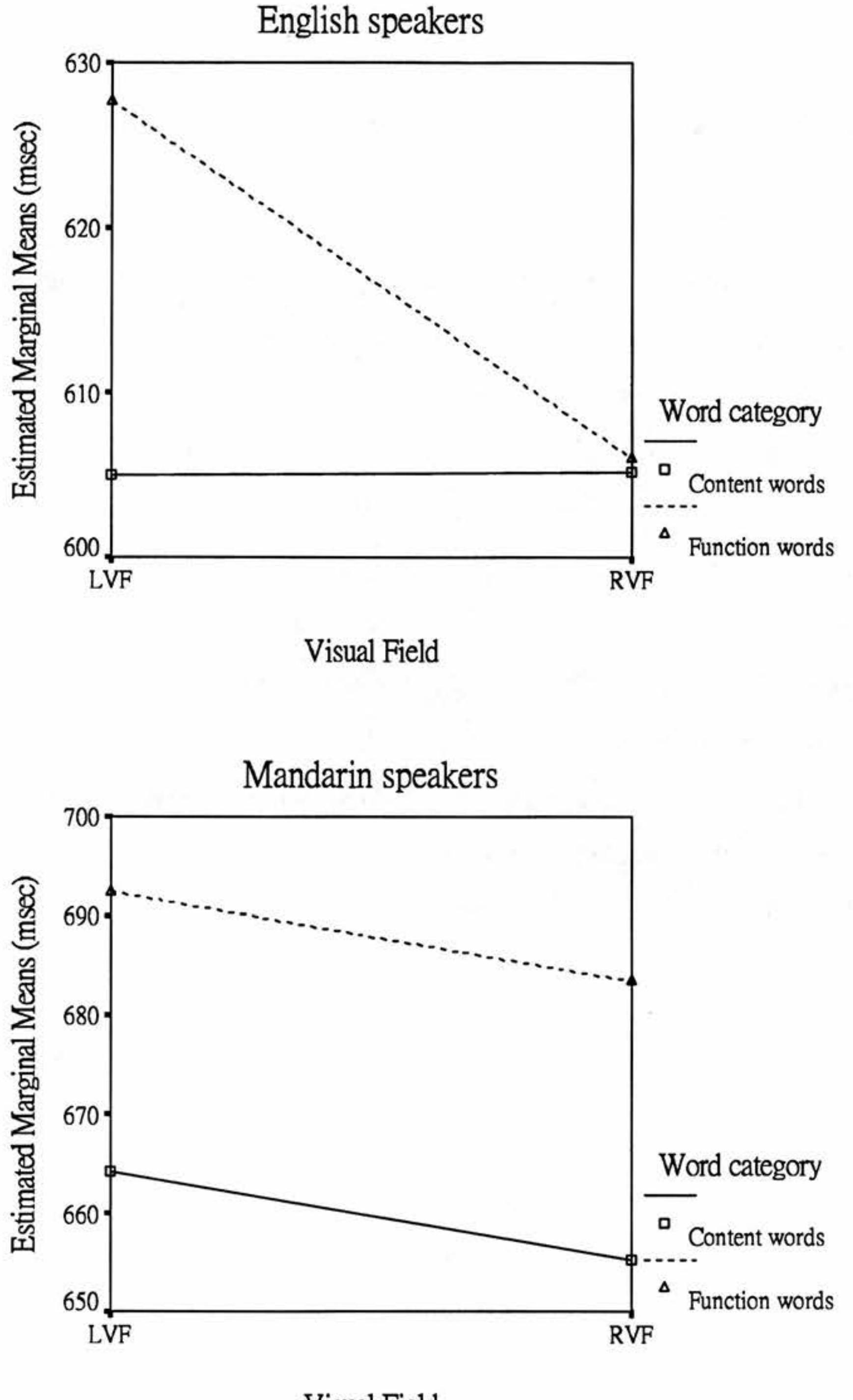


Figure 28. Function word advantage for English speakers, but not for Chinese.

4.4. Discussion and Conclusion

4.4.1. An RVF advantage for function words

The current experiment tested the RVF advantage in English word recognition and the RVF advantage for English function words by Chinese and English readers. As hypothesized, Chinese-English bilingual participants showed a marginally significant RVF advantage and an overall content-word advantage over function words, but no RVF advantage for function words. In contrast, English monolingual participants showed superiority in the recognition of function words presented in the RVF, akin to the results of Mohr, Pulvermüller and Zaidel (1994). The key findings are those of the Chinese-English bilinguals.

The fact that Chinese participants had shown a tendency towards the RVF advantage when reading English words excludes the strong claim that the information structure of the (English) lexicon plays no role at all. Given that the RVF advantage for Chinese words is debatable and inconsistent itself, Chinese readers may have accommodated to the salient information structure in English and/or had the same predisposition for alphabetic processing in the LH as native English readers. The information structure in English is asymmetric, with more information in the initial letters of the words and less in the later parts. From the perspective of the split fovea model, English words are divided between the hemispheres in order for each to obtain equal amounts of information, resulting in behavioural lateralisations. This salient information structure of English materials may have been adapted by Chinese participants, overwriting the unclear lateralization pattern in the processing of Chinese orthography and eliciting a marginally significant RVF advantage.

An alternative cause of lateralization in word recognition and/or an additional contributor to lateralization lies in the fact that phonological information is embedded in the orthography of English. The predisposition for alphabetic processing in the LH may lead to the marginally significant RVF advantage in the Chinese participants the same as in the native English readers. Overall, though, we have excluded the possibility that there is no potential role for the information structure of English affecting the development of word recognition in the Chinese readers.

4.4.2. Non-significant function word advantage in the RVF

In addition, Chinese participants did not show a RVF advantage for English function words. In the literature, the LH has long been known as a better syntax processor than the RH in English readers. In Chinese, although much of what is achieved by syntax in English is achieved by other means, we agree with Hoosain (1992) that there is no clear demonstration that the equivalent processing in Chinese is *not* in the LH. Hoosain (1992) argued that different languages or even different dialects do not occupy different processing loci within the brain. He also reported that several studies that had claimed a differential lateralisation of language functions in Chinese-English bilinguals might be due to other critical factors like presentation time of stimuli and the paradigm used. The default prediction might have been that Chinese-English bilinguals should show a RVF function word advantage. As we have shown, this prediction is not borne out by the data. Our own prediction was that readers are sensitive to the statistical profile of the language (a second language, in this case), and thus we might not see a RVF function word advantage that reflected pre-existing processing predispositions. Behaviour may result from the statistical profile of the language or from pre-existing predispositions. The absence of a RVF advantage for function words in the Chinese bilinguals implies that the constraints associated with the particular language are more to the fore.

Chinese function words

The Chinese language, a so-called analytical language, is characterized by an abundance of function words. However, the characteristics of Chinese function words differ massively from those of English. First of all, each Chinese character has only one form, which does not change according to number, gender, verbal inflection, conjugation, tense or case. Secondly, some Chinese prepositions originate from verbs and many of them still have some characteristics of verbs, or can even be used as verbs. Take a character 到 (dao), for instance; it can be considered as a preposition in the sentence 我要到倫敦 "I am *going to* London" or as a verb in 我們何時到(達)倫敦 "when will we *arrive* at London". To distinguish its function clearly is sometimes difficult. There is more difficulty, as Chinese function words co-occur mostly with content words. Furthermore, there are relatively few obligatory contexts for function words. In clinical data from Chinese-speaking agrammatic patients, morphological errors in free narratives of Chinese were seldom found. Patients can often find an alternative way to express the same grammatical function without using those morphemes that they have difficulty retrieving or using (Packard, 1990).

In short, there are radical differences in morphology between English and Chinese. The elimination of a RVF advantage in English function words might have come from the free morphology of Chinese, as discussed in the Introduction.

Semantic processing of lexical decision

Another possible reason for the absence of a RVF advantage for function words in the bilinguals we studied was that the Chinese participants did not have access to a processing mechanism for English syntax as strong as that of English native speakers. The semantic pathway is more reliably used in processing Chinese materials; indeed, the literature has shown a double activation of semantics and phonology and their complex interaction when dealing with Chinese characters (Feng, 1999; Perfetti, et al., 2002; Spinks et al., 2000; Weekes et al., 1998; Ziegler et al., 2000; Zhou et al., 1999a). Hence, Chinese participants might have made lexical decisions based on the meanings of English orthography. They might achieve the task by means of a more semantic pathway, *i.e.* basing the criterion for a response on the activation of rich meanings. Thus, recognising a content word 'house' is much easier than a function word 'which'. For this reason, function words may have been processed by the Chinese participants with more difficulty (shown by the longer response latency) and thus not as precisely and rapidly, compared with the English-as-first-language participants.

4.4.3. Conclusion

In conclusion, in this theme we have investigated the length effect of Chinese character recognition, and found a significant word-length effect but no interaction between Visual field and Word-length. We have also investigated the informational distribution of Chinese words which tend to be flat in the majority two-character words and asymmetric in the minority four-character words. In the current chapter, we have shown, for the first time, a tendency towards a RVF advantage for visual lexical decision in Chinese-English bilingual participants, which indicates that processing may reflect existing predispositions of the brain or it may reflect the informational profile of the lexicon being learned. Our result of a marginally significant RVF advantage in Chinese-English bilinguals (in the face of no such clear effect in the processing of Chinese) suggests the role of the information structure of the lexicon being learned. In contrast to this tendency towards a RVF advantage, there was no such advantage for function words in the Chinese-English bilinguals. The absence of this effect may be due to a number of factors, including morphological differences between the languages and a semantic strategy in visual lexical decision, but it serves as a point of comparison for the successful demonstration of the tendency towards a RVF advantage for words. This advantage may still be an indication of the role of the informational structure of the lexicon. In the next chapter we will start the second theme, the Bilateral effect, based on a model we propose and in line with the split fovea hypothesis, to examine the function of complexity in Chinese multi-character words discussed in the first theme.

Theme 2. The Bilateral effect

Chapter 5. The Bilateral Effect in the Recognition of Chinese Characters

Abstract

Researchers have shown a "bilateral advantage" for English words presented simultaneously and bilaterally in the two visual hemifields. Given that hemispheric lateralisation in Chinese does not appear to be as robust or as extreme as has been found in English, this experiment aims to examine the Bilateral effect with Chinese characters, based on hypotheses of task complexity, Gestalt perception, redundancy gain and foveal splitting. For the first time we propose a model based on hemispheric lateralisation and the split-fovea hypothesis to explain the advantage of bilateral presentation over unilateral presentation. The results show a tendency towards the Bilateral advantage with increases in word-length, indicating that only if the complexity of a task increases to a critical level will the two hemispheres collaborate to complete the task. The tendency of the Bilateral effect supports Gestalt perception, redundancy gain and the split-fovea hypotheses but is restricted to the longest word-length. (Part of this chapter has been published as Chou & Shillcock (2002a&b).)

5.1. Background

5.1.1. The definition of the Bilateral effect

The Bilateral effect is generally defined in two senses (Boles, 1995). One sense is the overall processing advantage when the same stimulus is presented simultaneously to both visual hemifields, as opposed to only one hemifield. This is the so-called difference between within- versus across-hemisphere processing, defined by Banich (1995). Another sense denotes the increase in a field difference, or asymmetry, that is found when different stimuli are presented to the two fields, as compared to a single stimulus in only one field (Examples can be found in Iacoboni & Zaidel, 1996, in which they showed two different items in the two visual fields and used an arrow to denote the target word and the distracter). Research in Chinese by Zhang and Feng (1998, 1999) and also the present experiment refer to the first sense.

For the causes of the Bilateral effect, no fewer than a dozen hypotheses have been proposed. Boles (1995) divided them into two broad classes: non-interaction hypotheses and hemispheric interaction hypotheses. In non-interaction hypotheses, it is proposed that the effect is an artefact of the way in which bilateral displays are processed by participants. In hemispheric interaction hypotheses, it is proposed that the effect is due to some type of interaction between the hemispheres, either inhibitory or facilitatory in nature, depending on the hypothesis. Both classes of hypotheses are concerned with interhemispheric transfer, integration, and cooperation.

5.1.2. The metacontrol studies in English

Mohr, Pulvermüller and Zaidel (1994) found a larger RVF advantage for function words than for content words, and also an advantage of content words compared to function words presented in the LVF (content word superiority in the LVF). As they reported, each hemisphere seems to be equipped with its own version of the lexicon. Thus, when two identical items are displayed simultaneously, one could expect interhemispheric inhibition, independence, cooperation, or a complex pattern of inhibition and excitation. Prior studies show that in certain cases there is evidence for a so-called "metacontrol" by one of the hemispheres in various linguistic and visual tasks. For example, in Hellige and Michimata's (1989) experiment, the letter comparison task showed that the performance pattern of the bilateral condition was similar to that found with the RVF presentation, suggesting that the LH is the dominant hemisphere in this task. Another experiment by Hellige et al. (1989) showed that behaviour in the bilateral condition in the recognition of CVC syllables was similar to that of the RH. These data suggest that the RH dominates the LH in this task. On the other hand, overall, there is a general tendency for the bilateral condition to give rise to an improvement in performance compared with either unilateral condition, constituting a bilateral advantage, or "superadditive" effect.

However, languages differ in the degree to which visual information matches specific phonological representations. In Spanish, with its shallow orthography, the letter patterns and the corresponding pronunciation are almost in a one to one correspondence (Bookheimer, 2001). Effectively it is possible for one to pronounce Spanish written words correctly without understanding their meanings. In contrast, pronouncing a Chinese character requires stored representations of each particular character, although most of the characters contain a phonetic radical which provides a cue, or varying reliability, to the phonological representation of the whole character.

Zhang and Feng (1998) investigated the Bilateral advantage of different linguistic materials apart from English. They used Chinese characters for the research and found that whether the Bilateral effect occurs depends on the attributes of the Chinese characters that readers have to process. If the task is to match two characters that were homophones or synonyms, then presenting those characters bilaterally at the same time produced superior results to presenting the characters unilaterally. In these studies participants were asked to press a Yes button with their index fingers when they saw two out of three simultaneously presented characters matching each other in orthography, phonology or semantics, or to press a No button when there was no such match, for presentations in which the stimuli stayed on the screen until a response was made. Matching pairs might be presented (a) unilaterally: within a visual hemifield with a distracter presented in the other visual hemifield, or (b) bilaterally: presented across the two visual hemifields with a distracter presented in either of the visual fields. Thus, every trial presented three characters, and two of them might be a matching pair. However, this bilateral advantage did not occur in matching visually similar characters. As Zhang and Feng (1998, 1999) showed, semantic and phonological attributes seem to require more difficult processing, compared to orthographic attributes. This pattern of results seems to reflect the computational complexity of the task: it is advantageous to have two hemispheres collaborating rather than one working alone for these more complex tasks. We discuss the interaction of task complexity with hemispheric interaction below.

5.1.3. The complexity of the task

As Mechelli, Humphreys, Mayall, Olson, and Price (2000) suggested, increasing word length increases the demands on both local feature and global shape processing. Reading Chinese is a complex task compared with reading alphabetic languages, due to the fact that the pronunciation of a character is not always identical to its phonetic radical, and also that in many cases the pronunciation of a character may change, depending on the character it combines with to make a morpheme. About 10% of the most frequently used

Chinese characters have more than one pronunciation. Their pronunciation changes with their meaning and may be resolved by the prior or the next character. For example, the character 長 is pronounced as 'chang2' in the word '長度' (length) and as 'zhang3' in the word '師長' (teacher). Thus, reading Chinese requires global processing on the character itself and also on the context in parafoveal vision.

Evidence obtained from split-brain patients supports the suggestion that interhemispheric processing aids task performance under high load conditions. Apparently, the difficulty of the task interacts with the strategy of hemispheric processing. When the difficulty of the task increases, patients who are not able to transfer information via the cortical commissures exhibit greater decrements in performance (Banich, 1995). In addition, when the task is lateralized to a single hemisphere, the performance of a split-brain patient tends not to be compromised much compared with that of normal participants. The fact that split-brain patients perform more poorly implies that normal individuals decrease heavy processing loads by distributing them across the hemispheres.

In a series of studies with normal participants, Banich et al. have shown that there is a bilateral distribution advantage (BDA) when participants solve more complex tasks, such as deciding whether two letters are pronounced the same, compared with when the task is less demanding, such as deciding when two letters are visually similar (Banich, 1998; Banich & Belger, 1990; Weissman & Banich, 1999). The advantage is ascribed to the division of labour between the two hemispheres; this division of labour can also be achieved if the processing is divided over time, that is, if the comparison is made over successively presented stimulus materials: Weissman and Banich showed that the BDA disappeared in these circumstances of sequential presentation and participants could make the relevant comparisons faster when materials were presented to just one hemisphere. Monaghan and Pollmann (2003) present simulations with a divided connectionist architecture showing that "hemispheric" collaboration emerges spontaneously with such architectures. They supported the finding that bilateral collaboration enhances the performance of difficult tasks. They simulated shape-matching and name-matching tasks using a connectionist model with divided computational resources to represent the two hemispheres. They showed that: first, the shape-matching task is easier for the model to learn than the name-matching task, as the amount of training needed for the latter task is more than that needed for the former. Second, they found a significantly better performance for bilateral than unilateral presentation of the name-matching task, and no difference in the effect of presentation for the shape-matching task. Third, the Bilateral advantage is a consequence of divided processing, and reducing interhemispheric resources lengthened the training necessary to simulate the behaviour.

Zhang and Feng (1992) have claimed that Chinese character processing is not only related to the number of character strokes but also the number of radicals within single characters. It has also been suggested by Chen et al. (1996), that radicals are the basic perceptual units in a character, and that the stroke pattern (the radical) is more crucial than the number of strokes in word recognition. This issue of the basic unit of word/character recognition is the subject of ongoing controversy in the study of visual word recognition. Pelli et al. (2003) and Pelli et al. (in press) have adopted a psychophysical approach to studying the recognition of letters and words in noise, comparing participants' abilities to recognize various alphabets, including Chinese. They demonstrated that alphabets vary in complexity, with readers processing more complex languages less efficiently than less complex languages. Pelli et al. defined complexity in terms of the perimeter of the letter/character squared over the "ink" area, measured in pixels. In line with the intuitions of readers, Chinese orthography was found to be more complex than English orthography. Pelli et al. defined efficiency with respect to an ideal observer. Pelli et al. (2003) reached the surprising conclusion that the brain's processing of words, as assessed by their identification in noise paradigm, was carried out over letter-units, despite the fact that the massive exposure to words over years of reading should have offered the possibility of processing being carried out over larger units. Instead, Pelli et al. have claimed that letters, and undefined sub-letter visual features (numbering some 20 for the alphabets covered) constitute the units over which independent processing occurs. Although Pelli et al. put forward the notion that this dependence on feature processing constitutes a processing bottleneck early on in the visual pathway in the processing of orthography, there are reasons to believe that this is not the whole picture. There are certainly levels of processing at which words are distinguished from orthographically legal nonwords; for instance, Cohen, Dehaene, Naccache, Lehéricy, Dehaene-Lambertz, Hénaff, and Michel (2000) have argued that the fusiform gyrus mediates the processing of whole words, labelling the region the visual word form area (VWFA). One of the reasons that Pelli et al. do not find processing over whole words at the relatively peripheral level addressed by their task may be that such entities are themselves divided over V1 in the two hemispheres and it is at this level that the relevant processing has to occur. In summary, Pelli et al. provide some psychophysical support for a smallish number of undefined visual features which have to be independently processed in word recognition, but the level of processing they address is lower than that of the systematic relationships that exist between words/characters/radicals on the one hand and phonology and semantics on the other hand. We suggest that it is these latter types of relationship that are important in the interhemispheric processing of Chinese characters.

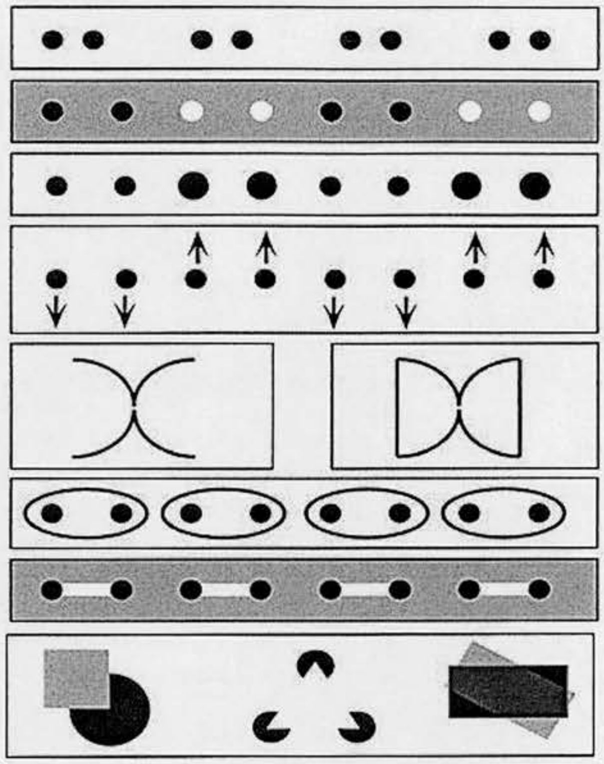


Figure 29. Examples of Gestalt perception.

5.1.4. Gestalt perception

An interpretation of the Bilateral effect with older historical roots is that the Bilateral advantage results from a Gestalt perception involving simultaneous presentations of the same item. As presented previously in the Introduction, Gestalt perception (Koffka, 1935) indicates that repeated objects have strong effects according to three Gestalt principles: Similarity, Proximity (or Contiguity), and Continuity. The principle of similarity states that things which share visual characteristics, such as shape, size, colour, texture, value or orientation, will be seen as belonging together. The principle of proximity or contiguity states that things which are closer together will be seen as belonging together. Take the first panel of Figure 29 for example; the eight circles in the panel are seen as two-by-two groups, because the horizontal rows of circles are close to each other. The principle of continuity predicts the preference for continuous figures. We perceive the central figure in the bottom panel as a triangle overlapping three circles instead of three separate circles each with a portion missing.

Doubly presented items are usually seen as a unit, according to the Similarity principle. Gestalt perception phenomena have usually been seen as relatively peripheral, perceptual phenomena, concerned with segmentation and "parsing" of the visual world. When applied to words or characters repeated in the visual field, this same perceptual processing leads to the two items being seen as related, but the extensive similarity/one-to-one mapping that exists in the case of repeated items seems to go beyond this issue of relatedness. It appears that the more detail that is repeated, the more scope there is for a perceptually compelling matching between the two items; for instance, characters containing more strokes, and words containing more characters, would appear to offer more scope for such a perceptual mapping. In the next section we explicitly address the issue of repeated words in the visual field.

5.1.5. Redundancy gain

As presented in the Introduction, Mohr and Pulvermüller (2002) introduced the notions of 'redundancy gain' and 'ignition priming' to represent, respectively, the advantage of simultaneous presentation of two identical items and the advantage of unsynchronised presentations with SOA 150~180 ms. These conditions facilitate word recognition leading to higher accuracy and shorter response latency in lexical decision, compared with other SOA conditions and regardless of left-right position of the stimuli. Based on a Hebbian cell-assembly framework (Pulvermüller, 1999), couched in functional terms, the 'redundancy gain' was explained as a result of the double activation of sensory cortices as neuronal summation devices; two versions of the same processing are simultaneously computed and then summed. The 'ignition priming' was explained as the synchrony of the onset of the second stimulus and the ignition of the neural representation of the first stimulus. However, one unexplored possibility is that the ignition priming might simply be a case of 'perceptual learning', *i.e.* things experienced more often are processed more easily. It is possible that the SOAs where the ignition priming was discovered were the duration for saccadic eye movements in normal reading - the time needed for eye propagation and back-propagation. Thus the acceleration effect of SOA 150~180 ms might simply reflect the fact that the eyes usually take 150~200 ms to remap letters or words during sentence reading under natural circumstances.

The current study is similar to the first experiment of Mohr and Pulvermüller (2002), where they compared two copies of identical words presented in both LVF and RVF with a single copy of a word presented unilaterally in the LVF or RVF. We hypothesize that the Bilateral effect will be observed in the double presentation of Chinese characters in a similar paradigm, although the differences between the reading of Chinese characters and alphabetic words is such that it is difficult to make predictions beyond the perceptual level. Additionally, the long response latency of lexical decision required by Chinese long words may affect the Bilateral effect (cf. Mohr and Pulvermüller's exploration of different SOAs).

5.1.6. A new model with the split-fovea hypothesis

As previewed in the Introduction, an interpretation based on hemispheric lateralisation and fovea splitting explains the Bilateral effect. Here we present a causal explanation of the Bilateral advantage according to fovea splitting, the possible eye saccades and the information transformation of images from the initial presentation of words in bilateral and unilateral conditions to the visual cortex.

Bilateral condition

For the bilateral condition, we propose Figures 30 to 33 based on the fact that the closer the stimuli are to the central fixation point, the clearer the image is (Anstis, 1974). In Figure 30, the initial eye fixation allows the information in the two visual fields to go to the two hemispheres. As a consequence, the right half of the stimulus in the LVF is transferred most clearly to the RH. Also, the left half of the stimulus in the RVF is transferred most clearly to the LH.

After an eye movement, word recognition typically involves a direct fixation on a single stimulus either in the RVF or LVF, depending on which way attention shifts. As shown in Figure 31, if a participant's attention shifts to the RVF after the initial bilateral fixation, then the recognition of the item in the right changes to a direct fixation. The right half of the single stimulus is transferred to the LH and the left half of stimulus is transferred to the RH.

When the eyes catch the image in the initial fixation, only the parts close to the fixation point are accurate images, the rest are less accurate. The bilateral presentation allows the two hemispheres to have a complete image of the characters. As a result, from two consecutive fixations, both the RH and the LH have a whole image of the stimulus. The bilateral presentation made the half images complete.

Unilateral condition

On the other hand, the information captured from the unilateral presentation is not as complete as that from the bilateral presentation. The initial eye fixation of the unilateral presentation is shown in Figure 32. When participants' initial fixation is at the central point, only the information of the right half of the stimulus in the LVF is projected to the RH. After the eyes move to where the stimulus is, the stimulus becomes directly fixated, allowing the information of the right half of the stimulus to be transferred to the LH and the left half of stimulus transferred to the RH, as shown in Figure 33. Eventually, for the stimulus presented unilaterally in the LVF, the RH captures the whole image, but the LH only captures the right half. Likewise, a stimulus presented unilaterally in the RVF would give the LH a complete image but the RH only the left half of the image. According to this model based on the split fovea hypothesis, the Bilateral advantage should occur in Chinese. Note that the typical division of phonetic complex characters in Chinese accentuates this effect compared with alphabetic languages.

5.1.7. Hypothesis of this study

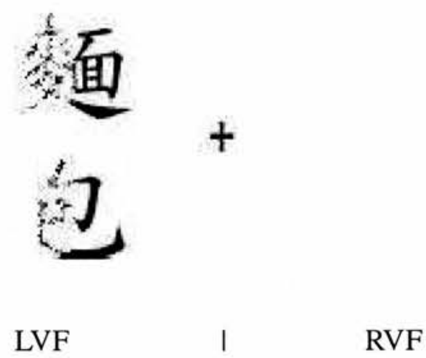
As has been addressed in Chapter 2, there is a robust word-length effect in the reading of Chinese words, and this length effect does not differ significantly between the hemispheres. If the absence of a length by hemisphere interaction in Chinese word recognition was due to the complex nature of words themselves, such as the dense information in words and intensive structure within characters, then we should find a bilateral advantage in the recognition of Chinese words, given that complexity seems to encourage the emergence of the Bilateral effect. Additionally, due to 'meta-control' (Section 5.1.2.) and the physical eye saccade model we have proposed, we believe the Bilateral effect should exist in Chinese. Furthermore, the vertical orientation of Chinese text means that Chinese words offer an opportunity for a Bilateral effect to emerge that is not found in English. In English, a vertical orientation for a word is atypical and unlikely to encourage normal reading behaviour; in contrast, vertical orientation in Chinese is normal. In the Discussion, we develop this analysis of the special relationship between Chinese reading and the Bilateral effect. First, though, we present the results of the experiment in which we tested the hypothesis that a Bilateral effect would emerge in the normal reading of Chinese words of different lengths. We conducted an experiment in which we controlled the complexity level, the

Information	RH(LVF)	LH(RVF)
Splitting	Right half	Left half
Non-splitting	Right half	Left half

Figure 30. Initial fixation of the bilateral presentation.

Information	RH(LVF)	LH(RVF)
Splitting	Left half + Right half in the parafovea	Right half
Non-splitting	Whole + Right half in the parafovea	whole

Figure 31. Secondary fixation of the bilateral presentation.



Information	RH(LVF)	LH(RVF)
Splitting	Right half	None
Non-splitting	Right half	None

Figure 32. Initial fixation of the unilateral presentation.

Information	RH(LVF)	LH(RVF)
Splitting	Left half	Right half
Non-splitting	Whole	whole

Figure 33. Secondary fixation of the unilateral presentation

number of characters contained in the word, and we used the bilateral paradigm to investigate the Bilateral advantage in Chinese words with multiple characters.

5.2. Experiment 4. Bilateral effect in Chinese

In this experiment we studied single words comprising multiple characters to investigate the Bilateral effect when word length was manipulated.

5.2.1. Participants

Twenty-five Taiwanese undergraduate and postgraduate students, eleven males and fourteen females, participated in the experiment. All of them were native speakers of Mandarin and right-handers with normal or fully corrected vision.

5.2.2. Stimuli

Materials were identical to those in Experiment 1, except that there were three presentation conditions, right unilateral presentation (as Figure 34), left unilateral presentation (as Figure 35) and bilateral presentation (as Figure 36) used in this study. Bilateral presentation denotes that two identical stimuli were presented in both visual hemifields simultaneously. Each presentation condition presented forty Chinese words consisting of two-, three- or five-characters in length. Words were presented 1.5 degree from the fixation point. An arrow occupying 0.6~0.9 degrees of vision angle from the central fixation point, was presented simultaneously with the Chinese stimuli. The arrow was to direct participants to respond to a particular word. This use of arrows was taken from Mohr et al. (1994).

A.

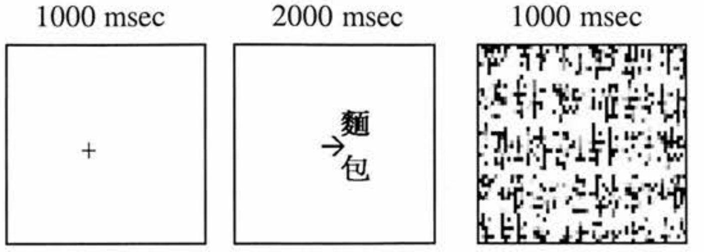


Figure 34. Unilateral presentation I: two-character words presented in the RVF.

B.

Figure 35. Unilateral presentation II: three-character words presented in the LVF.

C.

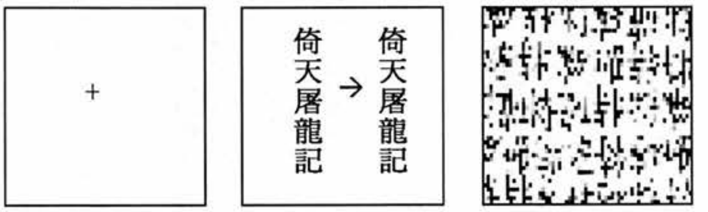


Figure 36. Bilateral presentation: five-character words presented simultaneously and bilaterally.

5.2.3. Procedure

The procedure was identical to that of Experiment 1. First, the fixation point was presented and lasted for 1000 msec, followed by 2000 msec of the stimulus and then 1000 msec of the mask picture. Participants were instructed to make a lexical decision and respond by pressing critical buttons with their index fingers. Pressing the rightmost button with the right index finger was required for realwords whereas pressing the leftmost button with the left index finger was required for nonwords.

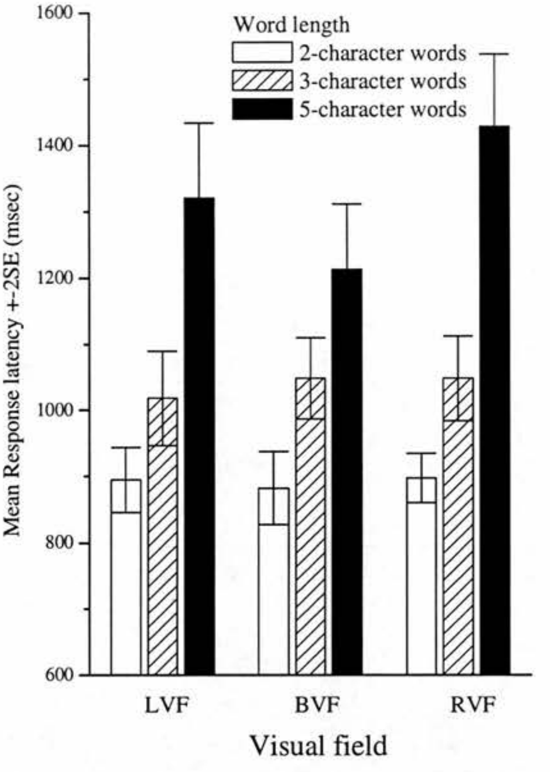


Figure 37. The overall result of Chinese bilateral experiment, by-participant analysis.

5.3. Analysis and results

In the by-participant analysis, two variables Visual Field (LVF, BVF and RVF) and Length (2-, 3- and 5-character words) were within-participant, whereas in the by-items analysis, Visual Field was a within-item variable and Word Length was a between-item variable. A repeated-measurement analysis was carried out in SPSS.

The results are presented in the following text, in Figures 37 and 38, and in Tables 19 to 23. A visual inspection of Figure 38 shows a V shape on the top line, a slighter effect in the middle line and a flat bottom line. This pattern suggests that the Bilateral effect was becoming more pronounced from the

Table 19. Descriptive statistics of Bilateral study.

VF	Word-length	Mean	Std. Error
LVF	2-character	854.77	49.20
	3-character	997.33	71.10
	5-character	1189.62	112.76
BVF	2-character	845.81	54.89
	3-character	952.12	61.07
	5-character	1069.47	98.15
RVF	2-character	827.65	37.59
	3-character	958.59	64.28
	5-character	1133.12	108.73

Table 20. By-participant analysis, tests of Within-Subjects Effects.

Source	Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	
VF	133482.50	2.00	66741.25	1.26	.29	
Error(VF)	2534603.73	48.00	52804.24			
LENGTH	3125389.60	2.00	1562694.80	13.81	.00	**
Error(LENGTH)	5432325.96	48.00	113173.46			
VF x LENGTH	86601.85	4.00	21650.46	.70	.60	
Error(Visual Field x LENGTH)	2978743.11	96.00	31028.57			

** The mean difference is significant at the .01 level

shortest words to the longest.

The analysis showed a significant main effect of Length (F_1 (2, 48) = 13.81, $p< .01$; F_2(2,47) = 11.17, $p< .01$). The Visual Field effect was not significant either by participants (F_1 (2, 48) = 1.26, $p> .1$) or by items (F_2 (2, 94) = .69, $p> .1$). Two-way interactions was non-significant between Length and Visual Field (F_1 (4, 96)= .70, $p> .1$; F_2 (4, 94) = .02, $p> .1$).

Table 21. By-item analysis, tests of Within-Item Effects.

Source	Type III Sum of Squares	*df*	Mean Square	*F*	Sig.
VF	37536.90	2	18768.45	.69	.51
VF x LENGTH	37536.90	4	654.98	.02	1.00
Error(VF)	2568196.25	94	27321.24		

Table 22. By-item analysis, tests of Between-Item Effects.

Source	Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	
LENGTH	1611477.04	2	805738.52	11.17	.00	**
Error	3389339.21	47	72113.60			

** The mean difference is significant at the .01 level

Table 23. Multiple Comparisons of the Word-length effect.

(I) LENGTH	(J) LENGTH	Mean Difference (I-J)	Std. Error	Sig.	
2.00	3.00	-151.60	54.00	.03	*
	5.00	-249.55	53.18	.00	**
3.00	2.00	151.60	54.00	.03	*
	5.00	-97.95	54.00	.20	
5.00	2.00	249.55	53.18	.00	**
	3.00	97.95	54.00	.20	

* The mean difference is significant at the .05 level

** The mean difference is significant at the .01 level

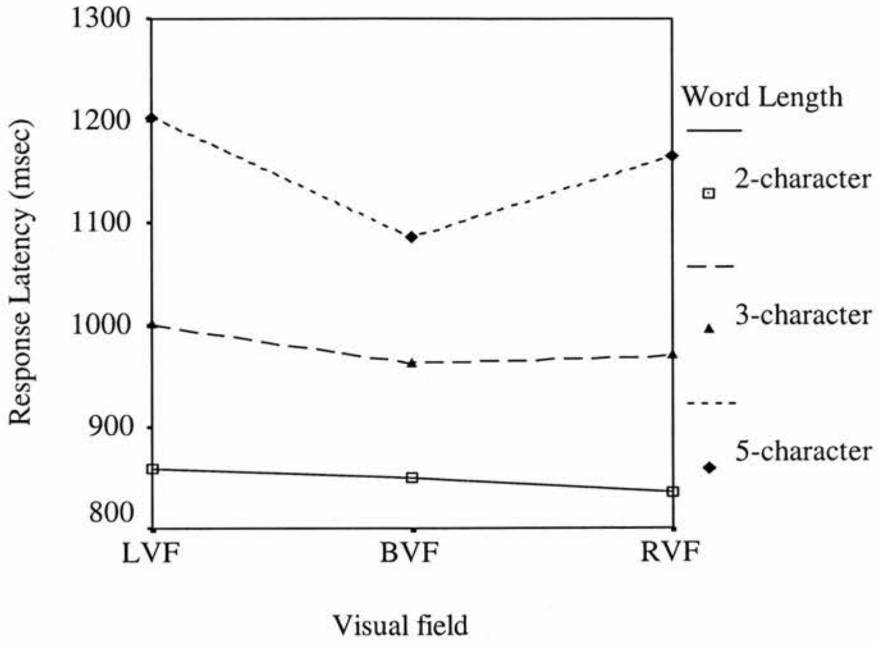


Figure 38. A tendency towards the Bilateral effect.

5.4. Discussion and conclusion

The results of this experiment showed that there was a tendency in the direction of greater word length increasing the Bilateral effect (Figure 38). Below, we discuss four factors that are potentially critical to the Bilateral effect in Chinese. They are (a) the complexity of Chinese words, (b) foveal splitting and the initial presentation of bilateral stimuli, (c) information in parafoveal vision, and (d) what we will term a Gestalt effect in perception.

5.4.1. Summary: a V-shape figure

As shown in Figure 38, there is a V-shaped relationship for the longest words, across the three viewing conditions. The shortest words, comprising two characters, represented the easiest task for recognition, and the response latencies in all three presentation conditions were nearly equivalent, resulting in a flat line. When word length was increased to three characters, the performance of word recognition in the three presentation conditions was slightly changed, indicating a tendency towards a RVF advantage. Most visibly, a V shape appeared when word length was increased to five characters. As we can see from Figure 38, the bilateral presentation produced the fastest responses.

5.4.2. Metacontrol

The response latencies of participants showed the tendency that the RVF unilateral performance was similar to the BVF performance, and the performance of LVF was slower tha RVF and BVF presentation. This result matches the theory of meta-control (in section 5.1.2.), by which the BVF performance is almost equivalent to the RVF performance, suggesting that the LH is dominant over the RH in this task, as was discussed in the Background 5.1.2. Matching the theory, the participants may be interpreted as having meta-control in the LH, and thus gave rise to similar RTs in BVF and RVF conditions across word lengths.

5.4.3. The increasing complexity of Chinese words

The tendency towards the Bilateral effect was observed in the longest words. This effect might have evolved with the increase in the complexity of the words. Mechelli et al. (2000) have reported that increasing word length increases the demands on both local feature and global shape processing. The complexity of words rises with the increase in word length. Further to the characteristics discussed in the Introduction, Chinese words are special with respect to word segmentation. To identify a word successfully and make a lexical decision, Chinese readers have to parse the individual characters into possible combinations of morphemes, as Chinese has equivalent inter-word and intra-word spaces. The possible combinations of a two-character word can be a one-character word plus another one-character word, or a two-character word itself, as we saw in Chapter 2. For example, a two-morpheme English word "watchstrap" requires a correct segmentation between the letter "h" and the letter "s" preceding a lexical decision (unless "watchstrap" is stored as a lexical item). The inter-character space of a Chinese word is equal for characters whether or not they are bound to a morpheme. Thus, when word length is increased to three characters, the numbers of possible segmentations increase to four, as shown in Table 24. The possible segmentations of a five-character word are shown in Table 25. A five-character word may comprise one to five morphemes, and each morpheme may be one or more characters. Thus there are 16 possible segmentations.

To handle an easy task, two hemispheres may work individually. However, to handle a more difficult task such as recognizing five-character words, the two hemispheres may be expected to be more likely to collaborate, resulting in the Bilateral effect. This aspect of Chinese reading is different from English word recognition, as some processing has to be carried out to parse the Chinese characters into words.

5.4.4. Gestalt perception and redundancy gain

This study showed an increasing tendency towards the Bilateral effect in the condition with the longest word length; a significant Bilateral effect emerged in one such subset of the analyses. A simple visual lexical decision task appears to benefit from bilateral presentation in a way comparable to the single-character homophone and synonym judgement tasks used by Zhang and Feng (1998).

A possible interpretation is that long words provide a greater number of identical units for comparison and enhance the Gestalt effect or redundancy gain, compared with simple words with smaller numbers of units (*cf.* Pelli, 2003). The five-character words used in this study were composed of a larger number

Table 24. Possible segmentations of a three-character word. Characters represented by the same letters belong to a morpheme.

3-character words	
One-morpheme word	AAA
Two-morpheme word	A BB
	AA B
Three-morpheme word	A B C

Table 25. The possible combinations of morphemes in five-character words.

5-character words	
One-morpheme word	AAAAA
Two-morpheme word	AAAA B
	AAA BB
	AA BBB
	A BBBB
Three-morpheme word	AAA B C
	AA BB C
	AA B CC
	A BBB C
	A BB CC
	A B CCC
Four-morpheme word	AA B C D
	A BB C D
	A B CC D
	A B C DD
Five-morpheme word	A B C D E

of strokes compared with the two-character and three-character words. Thus the Gestalt effect and redundancy gain rose with the increase of word length and reached its strongest level in five-character words.

As repeated items are presented simultaneously, they are seen as a unit or as having some connection, such as being part of the same object or as having a common fate. This Gestalt effect of perception involving the sheer number of stimuli presented in a display is confounded with the Bilateral effect; which is the best way of characterising the effect? Due to the problem of presenting two items at the same place and at the same time, Mohr and Pulvermüller (2002) presented two stimuli at the same place but asynchronously with SOA 100 to 300 ms in the central fixation point and reported in their fifth experiment the 'ignition priming' of word recognition at SOA 150 to 180 ms. However, they did not find a way to test the presentation of double stimuli presented at the fixation point but with zero SOA – the two identical stimuli would of course appear to be the same word. We will modify the design by transforming the two stimuli so that they are at different spatial scales, one embedded in the other, to achieve the goal of simultaneous presentation of two stimuli at the same fixation point. We will examine this paradigm in the next chapter. In further chapter, we will examine multiple numbers of characters which are displayed simultaneously in a Pop-Out paradigm (in a five by five array) to expand the sheer number effect with a unified spatial scale.

5.4.5. Foveal splitting

The initial bilateral presentation

According to the model based on the split fovea hypothesis discussed earlier, the bilateral projection in every bilateral trial (before viewers shifted their eyes to one or other of the stimuli) has consequences for the prolonged processing of long words. As seen in the results of the present experiment, the bilateral projection still tends to help word recognition even though it only occurs right at the start of the presentation. Effectively, for the largest proportion of the time that the five-character words are fixated, there is direct fixation on one or other of the two stimuli, but a Bilateral effect is strongest in this condition, counterintuitively.

Consider the first fixation, midway between the two identical stimuli. The two identical stimuli are visually registered, along with the arrow indicating which hemifield is to be attended to. For the longer words, it is very doubtful that the words, or even any of their component characters, are recognized at this point. The next fixation and all subsequent fixations fall on the characters of the attended word. Consider now the processing of the characters towards the end of the fixated word, and, in particular, a fixation dividing one such character. The left half of the character is projected to the RH and the right half of the character to the LH. Normal recognition would involve the hemispheric integration of these two sets of information. However, in the experiment we are reporting, the unattended word is still a potential source of information. If the fixated word is the left-hand stimulus, then the left side of the relevant unattended character is parafoveally available to the LH and is able to supply it with information complementary to that which it is currently fixating; *i.e.*, the LH has immediate visual information about the whole word, without relying on callosal transfer.

Foveal splitting and parafoveal vision

Two possible explanations were developed to explain this result, one involves foveal splitting and parafoveal vision, the other was termed redundancy gain. First, according to the model based on the split-fovea hypothesis we proposed in section 5.1.5, the initial stage of presentation must either accomplish more than the later stages, and/or have a facilitating effect.

This interpretation means that the Bilateral effect is prima facie evidence for foveal splitting, because (a) only if a word is divided into two halves at about the central point can the bilateral presentation provide a complete image in one of the two hemispheres and (b) only in the split-fovea model does the information projected to the hemispheres from the bilateral presentation differentiate the result from unilateral presentation (see the figure of second fixation of the bilateral presentation for details). As shown in Figures in 5.1.6, if the fovea and the fixated words were not split from the centre, *i.e.* words were perceived by an undifferentiated vision, then when words were directly fixated (during the second fixation), each hemisphere would have the information from the complete image. In the splitting fovea hypothesis, one of the hemispheres has a complementary image within-hemisphere in bilateral viewing condition, which advances the Bilateral effect to any other conditions. Unlike the splitting fovea hypothesis, in non-splitting fovea hypothesis, there is no difference between unilateral and bilateral viewing conditions because each hemisphere would have the same amount of information.

The information captured in parafoveal vision played an important role in the Bilateral advantage. In the bilateral presentation, this initial "preview" was believed to be bilateral, but when viewers read over the words and shifted their eyes to one of the stimuli, the other stimulus which was not directly fixated became the information in the parafovea. Combining the fact that the five-character words took the longest time, the final parts of the word had possibly attracted viewers' fixation and had the other word in the parafovea offering assistance to the target word recognition. Parafoveal vision might have contributed to the Bilateral effect in Chinese long words. We will further examine this assumption of parafoveal assistance in Chapter 7 by presenting multiple tokens of characters simultaneously in the background.

5.4.6. Conclusion and linkage to the next chapter

In short, there was a tendency towards the Bilateral advantage when word-length increased. The tendency indicates that only if the complexity of a task increases to a critical level will the two hemispheres collaborate to complete the task. In this study we have discussed the results with respect to metacontrol, complexity, Gestalt perception, Redundancy gain, and the fovea-splitting hypotheses. This effect was evidence of hemispheric collaboration when the tasks were of a heavy loading, supporting what Mohr et al. (1994) and Monaghan and Pollmann (2003) reported, that the left and right hemisphere could collaborate rather than inhibit each other or act independently when processing the same linguistic stimuli. However, it might be argued that the Bilateral advantage may not be generated completely by hemispheric collaboration, as there was a possibility that it may be generated by the assistance of parafoveal vision, the Gestalt perception of repeatedly presented stimuli, or the sheer number of stimuli in the presentation. To test these assumptions, we conduct two experiments in the next two chapters by presenting multiple stimuli in the centre of the visual field to examine whether the number of stimuli is related to character recognition, regardless of the manipulation of the visual fields.

Chapter 6. The Recognition of Overlapped Chinese Characters

Abstract

It remains uncertain to what extent the Bilateral effect is attributable to collaboration of the two hemispheres, or to Gestalt perception and redundancy gain that participants had experienced when two identical items were presented simultaneously. To resolve this issue, two overlapped Chinese characters were presented simultaneously in the centre of the computer screen, regardless of the manipulation of visual fields. We hypothesize that, if the Bilateral effect were due to Gestalt perception, the relative difference between two characters' recognition and one character's recognition should be significant. The results suggest no obvious link between the profound Bilateral effect and the hypothesized Gestalt perception. We suggest that the dissociation of different spatial scales of two characters may have occurred with the recognition of overlapped Chinese characters.

(Part of this chapter has been published as Chou & Shillcock (2002c).)

6.1. Background

Studies have shown that the brain may have different strategies allowing various aspects of perception to be processed independently, such as near and far, global and focal, and coarse and fine processing (Mack & Rock, 1998; Marshall & Halligan, 1995; Mozer, Halligan, & Marshall, 1997; Nazir, 2000). These strategies may be divided along hemispheric lines. Furthermore, there may be low-level, subcortical communications, contrasted with high-level cognition, allowing the sharing of information between the hemispheres and enabling the two hemispheres to work as a whole unit.

6.1.1. Near or greater viewing distance: a line bisection task

Mozer et al. (1997) reported that a participant with unilateral neglect showed impairment in a line bisection task when the line was at a near viewing distance. In contrast, this impairment was not found when the line was placed at a greater viewing distance. This observation suggests that there is a dissociation between the perceptions of items at a short or long distance. The two independent pathways allow the perception to be impaired in one kind but intact in the other. The underlying distinction may be between peripersonal and extrapersonal space.

6.1.2. Work as a complete unit: the split brains

In 1987, Sergent demonstrated low level pathways between the two hemispheres of split-brain patients. Her study showed that when presented with a four-letter word in the centre of the two visual fields, the split-brain patient would try to guess the word by the information that he had perceived from the RVF, even though there were only two letters. However, when there was a nonword presented in the centre of the visual field, the patient would directly name the two letters in the RVF, with the relatively accurate awareness that he had responded to the item as a nonword. Sergent speculated that participants might be doing some critical processing below the cortex. This subcortical processing allowed the disconnected brain to combine and integrate information in the two visual fields, and to have a reasonably high accuracy in a lexical decision task. On the other hand, this low level processing obviously had its limitations owing to the fact that the participants could not know which word was really presented.

6.1.3. Low level cognition: perceptual learning

Perceptual learning leads to improvements in some tasks such as word recognition. Nazir (2000) demonstrated that learning to recognize a visual item displayed at one single location in the visual field may help in recognizing this pattern specifically when displayed at the trained location. This was caused by the fact that the orientation and retinal location processed by lower visual areas matches the spatial organization of higher areas. The same result was extended to length effects. Nazir reported that, first, the length effect might depend on the frequency of having read printed words of various lengths displayed at different retinal locations. Second, only school students over grade seven had shown the length effect in word recognition. Third, recognition of English words presents a RVF advantage when word lengths are longer, however, the same advantage was not shown in Hebrew (Nazir, 2000), which is normally written from right to left. Effectively, reading experience, the familiarity of participants with a word (its word frequency), and perceptual learning in the early stages of recognition should both be taken into account in the study of high-level recognition.

6.1.4. Visual attention and the size effect

Instinctively, the size of stimuli is a factor in capturing attention: for instance, Mack and Rock (1998) report an experiment in which participants failed more often to see small circles, compared with large circles. Large sizes capture more attention, and the stimulus size bridges the low level characteristics, spatial scale, with the higher-level attention. In the current experiment, we assume that a large stimulus captures attention easier than a small one and so larger lexical stimuli are responded to faster.

6.1.5. Relationship to the previous bilateral presentation experiment

We have four aims in the design of this experiment. The first two are to test the familiarity/frequency effect (as mentioned in 6.1.3) and the size effect (as mentioned in 6.1.4) in Chinese character recognition. Thirdly, we presented overlapped characters, a large character with a small character embedded in the centre, to investigate processing at different spatial scales (as mentioned in 6.1.1 and 6.1.2). This effect has not been studied in Chinese (or English) so it is novel and worth examining. Finally, the aim of this experiment was to test the possible Gestalt perception effect and redundancy gain of the bilateral presentation discussed in the previous chapter. Previously, bilateral presentation tended to show some advantages in the recognition of long Chinese words. Yet it is uncertain whether the Bilateral effect was caused exclusively by the collaboration of the two hemispheres or by the Gestalt effect made by repeated items. We wish to investigate, in the present experiment, whether the recognition of two stimuli presented simultaneously in the centre of the screen regardless of the visual fields and at different spatial scales, accelerates word recognition.

6.2. Experiment 5. Overlapped characters

6.2.1. Hypothesis

The hypotheses we are testing are listed as below. First, large stimulus size captures visual attention, which should speed up the recognition of large characters compared with small characters. Secondly, character frequency should affect the speed of character recognition. Last but not least, if the Bilateral effect was due to a simultaneous presentation of two items, then when the ambient processing of the large character, and the focal processing of small characters are merged at the same time, the two simultaneously presented items should facilitate recognition.

6.2.2. Participants

Eleven male and fourteen female students participated in the experiment. All of them were native speakers of Mandarin and fluent in English with normal or fully corrected vision.

6.2.3. Stimuli

In this study, Chinese materials were presented in three different versions, a Large version (400 by 400, of the units in Psyscope), a Small version (50 by 50) and an Overlap version, in which a large character was overlapped by the same character in the small-version size in the centre (see Figure 39). As shown in Figure 39C, the centre of the large character was cleared beforehand in order to make sure that the small character was not obscured by the large one. The presence of the smaller character did not make the identity of the larger character ambiguous. Thirty-two characters were selected from *The most frequent nouns in journal Chinese and their classification: Corpus-based research series* (1993, by the Chinese knowledge information processing group). Half of the characters were ranked as high frequency (Frequency of occurrence is from 3510 to 10000 among the total occurrence 1568608 of 5182 characters) and another half as low frequency characters (Frequency <10). They were used in each presentation condition and assigned by a Latin square design. A mask picture was produced by overlapping characters, which were not used in the experiment, of the same size as the small version stimuli. Non-characters were

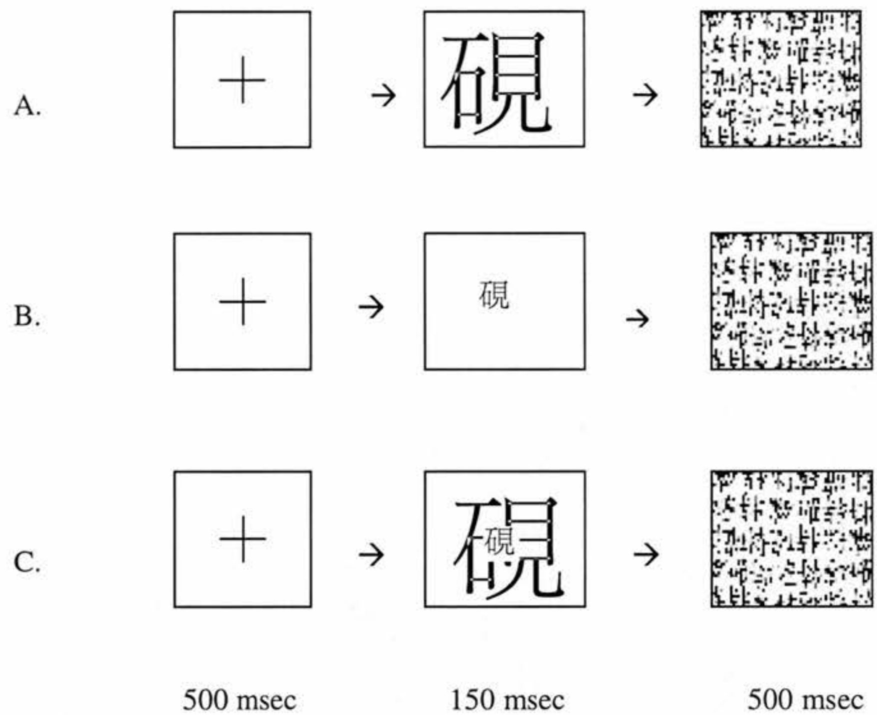


Figure 39. The design of overlapped stimuli: A: the single large version; B. the single small version; C. the Overlap version of stimuli.

made by inverting the strokes of normal characters that were not used in this experiment.

6.2.4. Procedure

As shown in Figure 39, participants saw a fixation cross at the beginning for 500 msec and then a stimulus picture for another 150 msec, followed by a mask picture for 500 msec. They were instructed to make a lexical decision as soon as possible by clicking the right-hand-side button on the response box for correct characters and the left-hand-side button for non-characters. Participants knew that both characters would always be the same in the overlapped condition. The stimuli and response times were presented and recorded using Psyscope software.

6.2.5. Design

In this experiment, the three conditions of stimuli sizes and two conditions of word frequency were within-participant variables. Each participant saw every character in one of its size conditions, presented at random. The instruction for participants was to place their index fingers on the right and left button on a response box. When the trial started, they had to fixate their eyes on the centre of the monitor where a fixation point was presented, and then to make a lexical decision as soon as possible whenever they saw a character presented on the monitor. The character disappeared after its presentation period of 150 msec or after participants making a critical response, and then participants would see a mask picture and another trial started again. Participants' fingers and the response buttons were counterbalanced between participants. Half of the participants were to press the right button with the right index finger for real characters, and to press the left button with the left index finger for non-characters. Another half of the participants were to press the left button with the left index finger for real characters, and to press the right button with the right index finger for non-characters.

6.3. Analysis and results

A two-way ANOVA was carried out both by participants and by items. In the analysis by participants, Frequency and Size of characters were within-participant variables, whereas in the by-items analysis, Frequency and Size were between-participant variables.

Figure 40 and Tables 26 to 29 show the results of this experiment. The frequency effect was significant by participants and by items ($F_1(1, 19) = 20.75$, $p < .001$; $F_2(1, 54) = 8.14$, $p = .01$). The size effect was significant only by participants but not by items ($F_1(2, 38) = 7.65$, $p < .01$; $F_2(2, 54) = 1.32$, $p > .1$). The two-way interaction between Frequency and Size was non-significant in the

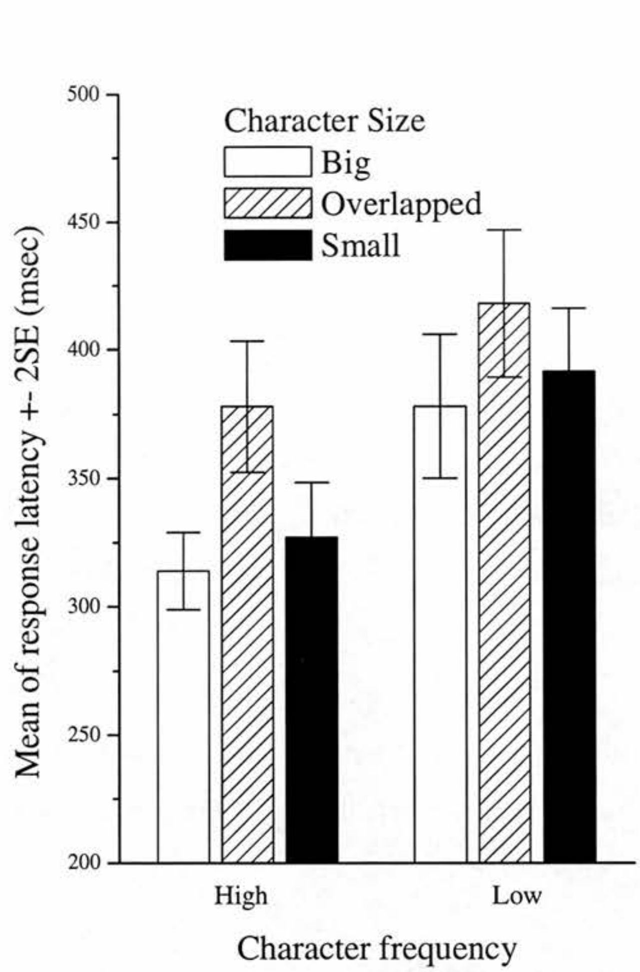


Figure 40. The results of the Overlapped characters experiment.

Table 26. Descriptive statistics of Overlapped characters.

FREQ	SIZE	Mean	Std. Error
High	Big	313.84	15.00
	Overlap	377.93	25.53
	Small	327.04	21.41
Low	Big	378.05	27.97
	Overlap	418.07	28.67
	Small	391.73	24.30

Table 27. By-participant analysis, tests of Within-Subjects Effects.

Source	Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	
FREQ	95252.43	1.00	95252.43	20.75	.00	**
Error(FREQ)	87212.25	19.00	4590.12			
SIZE	58419.62	2.00	29209.81	7.65	.00	**
Error(SIZE)	145095.89	38.00	3818.31			
FREQ x SIZE	3942.50	2.00	1971.25	.48	.62	
Error(FREQ x SIZE)	154886.15	38.00	4075.95			

Table 28. By-item analysis, tests of Between-Item Effects.

Source	Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	
FREQ	29142.81	1	29142.81	8.14	.01	*
SIZE	9440.84	2	4720.42	1.32	.28	
FREQ x SIZE	1435.01	2	717.50	.20	.82	
Error	193252.79	54	3578.76			
Total	8796339.02	60				

Table 29. Multiple Comparisons of the size effect, by-participant analysis, LSD test.

(I) SIZE	(J) SIZE	Mean Difference (I-J)	Std. Error	Sig.	
Big	Overlap	-52.06	13.81	.00	**
	Small	-13.44	13.83	.34	
Overlap	Big	52.06	13.81	.00	**
	Small	38.61	13.81	.01	*
Small	Big	13.44	13.83	.34	
	Overlap	-38.61	13.81	.01	*

* The mean difference is significant at the .05 level

** The mean difference is significant at the .01 level

by-participant analysis ($F_1(2, 38) = .48$, $p>.1$) or by-items analysis ($F_2(2,54) = .20$, $p> .1$).

6.3.1. Post hoc t-tests for simple effects of frequency and size

The frequency effect was significant both by participants and by items. As shown in Figure 40, high frequency characters had superiority in recognition over those of low frequency. A size effect was only found in the analysis by participants. Post hoc tests showed that both big and small characters were recognized quicker than overlapped characters ($p= .001$ between overlapped and small characters, and $p= .012$ between overlapped and big characters), yet the difference between response latency of big and small fonts was non-significant ($p= .34$).

6.4. Discussion and conclusion

This experiment aims to investigate whether the Bilateral effect was due simply to the fact that two stimuli were presented simultaneously, regardless of the fact that they were presented in different visual fields. If the Gestalt perception phenomena were occurring, a stimulus made of a large and a small visual items might cause autonomous processing of the character at the two different spatial scales, causing eventual facilitation to the recognition. Equally, large and small characters might tap into processing at different spatial scales. The results showed that the overlapped characters took a longer time for recognition than for the individual characters in either large or small fonts. There was no tendency for participants to tend to perform in the way suggested by the Gestalt perception hypothesis.

6.4.1. Visual attention

Visual attention factors facilitate the recognition of large stimuli. In this study, the large characters tended to be recognized faster than the small characters, though this difference was non-significant. This result did not falsify our hypothesis that visual attention was more likely to be captured by larger objects, compared with smaller objects. The recognition of Chinese characters seems to involve this size effect.

6.4.2. Interference of spatial scale

Big characters tended to be recognized slightly quicker than small characters in the by-participant analysis. However, there were big characters in the overlapped versions, but the overlapped version was not recognized as fast as the individual big characters. Apparently, in the overlapped version, the small characters interfered with recognition.

6.4.3. Dissociation between perception of near and far

Big and small characters in this experiment were supposed to be equivalent to objects placed closely and far away, according to the consistency of size. In this experiment the non-significant size effect may result from all the stimuli being presented on the monitor screen. Participants may treat them as items in an equivalent distance. Simply presenting large and small versions of the same character simultaneously is not sufficient to trigger differential processing that has evolved for near versus far visual stimuli.

6.4.4. Subversion of Gestalt-style perception

The processing of characters across two spatial scales was not accelerated as simply as the method we used in this experiment might imply. That was either because we did not design the stimuli appropriately or because there is no combination of word recognition processes, leading to eventual facilitation. These conclusions showed that the simultaneous presentation of two different-sized variants of the same stimulus did not accelerate recognition, or, in other words, the two stimuli did not seem to help each other. This supports the existing interpretation of the Bilateral effect: that separate processing occurs by virtue of the projection of the stimuli to separate hemifields.

6.4.5. Conclusion

To reprise the four aims in this study on the Bilateral advantage (section 6.1.5.), we can reasonably conclude that, first of all, the frequency effect was significant, indicating that high frequency characters enhance word recognition. This is a reliable result in the literature and confirms the effectiveness of the study. Secondly, the size effect causing faster recognition of large stimuli than small ones indicates that different perceptual spatial scales have different impacts on character recognition. We would assume that character sizes should be comparable in order to achieve the full advantages of bilateral recognition. Thirdly, when presented overlapped characters in large and small fonts, Chinese readers could not ignore the effect caused by the different spatial scales. Lastly, two identical character stimuli which were presented simultaneously at different scales did not automatically accelerate recognition according to the results of this experiment. The bilateral advantage was not produced by there simply being two items, at least not by an overlapped presentation of a large and a small item. Rather, overlapped characters lengthened the response latency and seemed to interfere with the recognition process. This interference might be caused by the dissociated perception of large/small (or closer/further) objects. To exclude this interference, the next experiments united the spatial scales of characters and adapted another paradigm with numerous Chinese characters to investigate the effect of multiple numbers of stimuli to Chinese character recognition.

Chapter 7. The Pop-Out Effect: Presentation of Multiple Characters

Abstract

In the previous chapters we hypothesized that the Bilateral effect might simply result from Gestalt perception involved in the double presentation of items, as repeated objects cause strong visual effects such as being seen as a unit or as having some connection. In the previous chapter we established that two centrally presented characters at different spatial spatial sizes did not accelerate the recognition task. However, there might be an interfering factor, spatial scale, involved in the word recognition task. The present study equalises the spatial scales to investigate the Bilateral effect and Gestalt perception by using multiple versions of Chinese characters. We adapt the Pop-Out paradigm by presenting a target character, highlighted in light grey and surrounded by 24 versions of the same or different character in dark grey. This paradigm allowed the participants to discover the critical stimulus preattentively. Participants make a lexical decision of the target character when it automatically pops out from the contrasting background. The result shows a significant background effect, suggesting that the information in parafoveal vision, provided by numerous versions of a character in the background, might elicit Gestalt perception, accelarate target character recognition, and contribute to the Bilateral advantage.

7.1. Introduction

There is a tendency towards a Bilateral Effect in Chinese, and it is more likely to occur for more complicated characters. This finding is in agreement with the more general finding that the two hemispheres are more likely to co-operate in processing if the task is a hard one compared with if the task is an easy one. However, it is also possible that there is a lower-level, perceptual contribution to the effect. Possibly it was the multiple stimuli themselves, rather than the cross visual field presentations *per se*, that resulted in the tendency towards a Bilateral advantage. In the previous chapter, we investigated the presentation of two simultaneously and centrally presented versions of the same Chinese character on different spatial scales, and found that recognition was not necessarily quicker for two characters than for a single character. The current experiment presents another special case of multiple presentations of characters, this time employing the Pop-Out paradigm (Treisman & Gelade, 1980; Treisman, 1988). We examine multiple versions of Chinese characters on the same spatial scale, to investigate whether the Bilateral advantage could have been wholly or partly due to multiple stimuli being presented simultaneously.

When a character is perceived, there is a contribution from the processing of both low and high spatial frequencies. In the former case, pre-attentive visual processing, probably of a magnocellular kind, can recognize where the character is on the page, and can possibly recognize that it is indeed a character. More detailed information about the identity of the character requires more high spatial frequency information. In general, the ease of perceptual processing is determined by what Attneave and Arnoult (1956) have called "perimetric complexity", which is the square of the inside-and-outside perimeter divided by the "ink" area (see Pelli et al. (2003) for further discussion.) Very finegrain visual processing is more likely to be carried out by the parvocellular system, but it is an empirical question as to whether fast magnocellular processing can provide information that can help identify the character when used along with the finegrain information provided by the slower parvocellular system. The search task used by Yeh (2000), see below, suggests that when participants are asked to find one particular Chinese character among many distracters, there is not a Pop-Out Effect: the number of distracters is still critical, in that the task takes longer with more distracters. It seems that the search task is easier if a more fundamental visual dimension is used (Yeh, 2000).

In the experiment we present below, we use a Pop-Out paradigm, in which the target character is light grey and the distracters are all dark grey. Participants are able to recognize the target character pre-attentively. Their task is a visual lexical decision on the target character. We test the hypothesis that this visual lexical decision will be facilitated by the presence of the same character occurring as the distracters, compared with the condition in which the distracters were not the same character. In the classic Bilateral Effect, the two stimuli have the same status as visual stimuli: they are visually identical, and are in fact interchangeable, and the participant has to respond to the one indicated by an arrow. In the paradigm we use here, the target and distracters have a fundamentally different visual status. It is less clear that the target will be facilitated by the other versions of the target. We also manipulate the frequency of the target characters, to provide extra information about the timescale of any facilitation; the slower processing of the low frequency target characters provides more scope for facilitation by the other characters in the visual field.

7.1.1. Pop-Out detection

Defined by Treisman and Souther (1985), Pop-Out is the perception involved in the recognition of a target character among distracters. According to Treisman and Souther, Mack and Rock (1998) and Yeh, (2000), the perception of Pop-Out generally occurs when one distinct target is presented in a group of any number of distracters; the target is seen as odd or standing out. Pop-Out may be based on the detection of local differences between an element and those that are in its immediate vicinity. Treisman and her colleagues carried out a series of Pop-Out experiments (Treisman & Gormican, 1988; Treisman & Schmidt, 1982; Treisman & Souther, 1985) and reported that targets defined by substantially different values on quantitative dimensions such as length, contrast, and line curvature were detected easily by parallel processing. Parallel processing in their terms means that the detection of a target will not be affected by changes made to the background, such as in number of elements in the background.

A similar design to the Pop-Out paradigm was used in a study of Chinese character recognition by Yeh (2000). In her study she categorized Chinese characters by their structure into two dimensions: horizontal versus vertical, and enclosed versus open, and assumed that the recognition of characters that differed across dimensions was faster than ones that differed within dimensions. In her experiment a target character was surrounded by multiple versions of distracters in a structure different from or the same as the target. For instance, a vertically-defined target might be surrounded by distracters defined horizontally in the former manipulation, and surrounded by distracters also vertically defined in the later one. The only factor Yeh manipulated was Dimension, as she did not use factors like colour, or contrast of characters. The target character stimuli were presented in a set of 7 or 23 distracter characters for as long as participants liked, and the task was to judge whether a target character was present or absent in the set. Yeh analysed reaction times and found that the number of distracters had a significant effect on the processing of the characters. This indicated that recognition in this study was not a parallel process as suggested by Treisman for the Pop-Out effect. Thus the crucial processing in the recognition task was not exclusively preattentive. In accord with this, in the present study we used the Contrast factor to distinguish the target character from its distracters by using light grey, in contrast to the dark grey distracters.

7.1.2. Frequency effect

Mack and Rock (1998) added in the factor of Familiarity into the Pop-Out detection, as they found that recognition of a familiar object, such as a Z, among unfamiliar distracters such as rotated Ns, improved performance, whereas the reverse was not true. Additionally, the Pop-Out effect was greater in the recognition of participants' own names than others' names; this demonstrated that the Pop-Out was caused not only by colour, contrast, length and number, but also involved familiarity. To clarify the role of familiarity in the Pop-Out effect, the current experiment employed characters of high usage frequency and low usage frequency.

7.1.3. Gestalt perception effect

We wished to test the hypothesis that a Gestalt perception phenomenon would speed visual lexical decision for Chinese characters when the target character appeared in a background of like characters in a Pop-Out paradigm. By Gestalt perception, we mean that the congruent forms of the target and distracter will facilitate visual processing of the target, even though the participants are able to find the target very fast, due to Pop-Out processing. The critical processing in the Pop-Out effect occurs very quickly; it is probably largely a subcortical phenomenon (Nazir, 2000), which requires little processing through cortical higher-level functions such as memory. In the Different background condition, the target character will pop out from the distracters by its contrast; whereas in Same background condition, the target character will pop out and, additionally, yield the Gestalt perception of distracters and the target. If the identical distracters facilitate target character recognition, then we can conclude that a Gestalt perception effect may have contributed to the Bilateral effect.

In summary, the participant is very quickly able to detect the stimulus (by virtue of the Pop-Out effect) about which she/he is to make a visual lexical decision. If that decision is speeded by the presence of the same background, then we know more about the nature of facilitation when there is more than one stimulus on the screen: we know that the facilitation can come from a stimulus of a different status and can have an effect in the earliest stages of perception.

7.2. Experiment 6. Pop-Out effect

7.2.1. Two background conditions

The aim of this experiment was to support the claim that the Bilateral effect might receive some contribution from a Gestalt perception effect. In contrast to the design of the "overlap" experiment in the previous chapter, we use characters of the same spatial scale in the current experiment; the characters in the current experiment should share more processing by virtue of the fact that they are on the same spatial scale. We designed the stimuli so that each one was a target character surrounded by 24 background characters. The background conditions were either 24 versions of the target character itself (Same background condition) or 24 versions of another character which was different from the target (Different background condition). The number and the physical size of the background characters was always the same.

7.2.2. Participants

Ten male and eleven female Taiwanese students at the University of Edinburgh took part in this experiment. All were of a closely similar educational and social background and skilled readers of traditional Chinese with normal or fully corrected vision. One male and one female were self-reported as

Figure 41. The layout of stimuli. Upper graph: Same background condition; Lower graph: Different background condition.

left-handers, the rest were right-handed or strongly right-handed. Handedness was assessed by *The Edinburgh Handedness Inventory (Oldfield, 1971)*, together with family history: if a right-handed person had any family member who was left-handed, he was grouped as right-handed, rather than as strongly right-handed. Only data made by strongly right-handed were included in the analysis. In total, the data made by 16 participants (8 males and 8 females) were taken into analysis.

7.2.3. Design

Within-participant variables were two levels of Character frequency (high and low), two levels of Wordness (real characters and non-characters) and two levels of Background (the same or different). The position of target characters was randomly chosen from the 25 possible positions.

The stimuli were 96 Chinese characters consisting of 50% high-frequency characters and 50% low-frequency characters. Characters and frequencies were based on *The most frequent nouns in Journal Chinese and their classification (1993)*. High-frequency characters were defined in this study as single-character words with frequency of occurrence higher than 3500 times, whereas low frequency characters were those with frequency below 15 times among 9 million words or, equivalently, 20 million characters. Each character was randomly assigned to one of the two background conditions: Same or Different background. As shown in Figure 41, upper graph: target character surrounded by 24 versions of the target character itself, except that the background characters were in dark grey, and the target character was in light grey; lower graph: target character surrounded by 24 versions of another character which is different from the target. Non-characters were made by removing one stroke from normal characters. A real character target was always surrounded by real characters in the same frequency level, and likewise, a non-character target was surrounded by non-characters in the same frequency level. The frequency was matched before real-characters were transformed to non-characters. Effectively each frequency level had half non-characters and half real-characters.

The fixation point was a 4 x 4 mm cross, Font: Bodoni MT Ultra Bold. Size: 24. Duration 1000, presented in the centre of the monitor screen. It was to draw participants' attention and fixate their eyes on the centre. A masking picture was produced by overlapping dozens of Chinese characters that did not appear in the formal experiment. The formal experiment was preceded by 18 practice trials. All the materials were produced by PhotoShop, and presented by SuperLab Version 1.2b5 (1994) on a Macintosh computer. Each picture contained 25 characters including a target character in light grey and all other background characters in dark grey. A target character could appear in any of the 25 positions. This is to prevent participants from anticipating and pre-fixating their eyes on a particular point.

7.2.4. Procedure

The sequence of presentation was, first, a fixation point, presented centrally on the screen for 1000 msec, followed by a stimulus picture made of 25 characters, which was then ended by a critical response or automatically after 500 msec. Afterwards a masking picture was presented for 1000 msec. The participants' task was to make a lexical decision as quickly and accurately as possible when they saw a target character pop out among 24 other characters in the background. Participants were seated at a distance of 450 mm to 550 mm, from their eyes to the monitor. The right-handed participants were instructed to make a lexical decision by pressing the right button with the right index finger for realwords and pressing left button with the left index finger for nonwords. Left-handed participants pressed the left button with their left index finger for realwords and pressed the right button with the right index finger for nonwords. A computer with millisecond precision recorded their response latencies.

7.3. Analysis and results

A two-way ANOVA was carried out by participant with Background and Character Frequency as within-participant variables. A by-item analysis was also carried out, with Frequency as a between-item variable and Background a within-item variable. Only right handers were included in the analysis.

The By-participant analysis shows a significant main effect of Background ($F_1(1, 15) = 5.37$, $p<.05$), a non-significant effect of Frequency ($F_1(1, 15) = .01$, $p>.1$) and a non-significant interaction of Background and Frequency. (see Tables 31 to 33 for details).

In contrast, in the by-item analysis no significant main effects were found, for the Background effect ($F_2(1, 14) = 2.4$, $p> .1$), for the Frequency effect

Table 30. Descriptive statistics of Pop-out study.

BG	FREQ	Mean	Std. Error
Same	High	383.71	47.55
	Low	344.33	48.31
Different	High	425.27	61.39
	Low	455.35	53.33

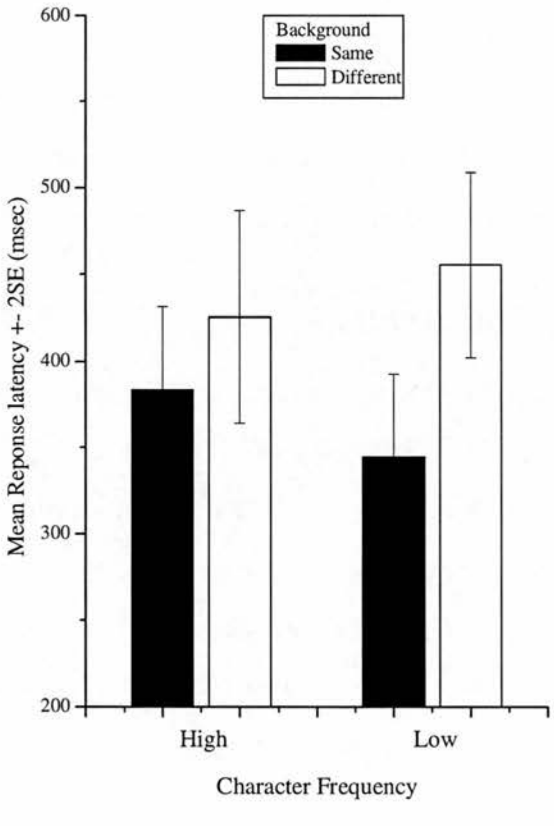


Figure 42. The overall result in the Pop-Out experiment, by-participant analysis.

Table 31. By-participant analysis, tests of Within-Subjects Effects.

Source	Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	
BG	93124.88	1.00	93124.88	5.37	.03	*
Error(BG)	259952.91	15.00	17330.19			
FREQ	345.43	1.00	345.43	.01	.92	
Error(FREQ)	444060.01	15.00	29604.00			
BG x FREQ	19298.67	1.00	19298.67	1.09	.31	
Error(BG x FREQ)	265519.46	15.00	17701.30			

* The mean difference is significant at the .05 level

Table 32. By-item analysis, tests of Within-Subjects Effects.

Source	Type III Sum of Squares	*df*	Mean Square	*F*	Sig.
BG	39885.12	1.00	39885.12	2.40	.14
BG x FREQ	1648.31	1.00	1648.31	.10	.76
Error(BG)	232673.18	14.00	16619.51		

Table 33. By-item analysis, tests of Between-Item Effects.

Source	Type III Sum of Squares	*df*	Mean Square	*F*	Sig.
FREQ	2384.728	1	2384.73	.19	.67
Error	177432.600	14	12673.76		

($F_2(1, 14) = .19$, $p > .1$), nor for the two-way interaction ($F_2(1, 14) = .10$, $p > .1$).

7.4. Discussion and conclusion

To sum up, first, participants were able to use a low spatial frequency cue to detect the target characters in a field of distracters, as has been shown in past experiments using the Pop-Out paradigm (*cf.* Treisman & Gormican, 1988). Such a search is assumed to work very quickly, and pre-attentively, using the magnocellular system. The participants in the present experiment used such a search to find the critical Chinese character, to which they then attended – processing both high and low spatial frequency information – and responded with a visual lexical decision. We hypothesised that multiple versions of the critical character in the background would facilitate the recognition of the critical character. This was a generalised version of the bilateral task: instead of just one other (bilaterally presented) identical stimulus appearing in the visual field, multiple versions appeared, in the current experiment. The classic bilateral experiment uses two visually identical stimuli (Mohr et al, 1994) which need to be processed using high spatial frequency information, and an arrow between them (which must be interpreted) denoting the critical stimulus. In the current experiment, we allowed the participants to discover the critical stimulus preattentively, thereby reducing the time spent in searching and in interpreting the arrow (and possibly processing the non-critical stimulus). In this sense, the role of the non-critical/background stimuli is potentially reduced in the current experiment, compared with the classical bilateral experiment, making facilitation less likely. Our prediction was that facilitation would still occur, and, further, that it may occur more when there were more points of correspondence between the critical stimulus and the (identical) background characters; i.e., when the characters are visually more complex. In some conditions of the experiment, which we discuss in more detail below, the non-critical parafoveal stimuli acted so as to facilitate the visual lexical decision.

Participants showed significant facilitation in the Same Background condition, compared with the Different Background condition. This result indicates that the decision is speeded by the presence of the same background, the nature of facilitation is from there being more than one version of the stimulus on the screen; together they have an effect in the earliest stages of perception.

The classic Bilateral effect was not significant in Chinese characters (Experiment 4). In the classic bilateral presentation a target word is presented with the other version of the word to the right or the left of the target. The absence of a bilateral advantage for Chinese characters might be constrained by the dense information contained in single characters. In this chapter a target character was surrounded by 24 versions of identical characters spread around the visual fields, the effect from the background stimuli to the target is stronger than that of the single 'background' stimulus in the bilateral presentation. The present study has confirmed this significant background effect, and demonstrated a convincing redundancy effect for Chinese characters.

Figure 42 illustrates that the core effect is found with the participants responding to the low frequency characters. Although the interaction between Background and Frequency was not significant, one of the reasons for the tendency of frequency effect in low frequency characters may lie in the difference in complexity between the high and low frequency characters: the low frequency characters (mean number of strokes = 11.41) were more complex than the high frequency characters (mean number of strokes = 9.09). This complexity makes Gestalt-like perceptual support more likely in the low frequency characters: there are more points of correspondence between the characters, critical and non-critical alike. In the Bilateral study, the Bilateral advantage was not found in two- and three-character words but was more evident in highly complex five-character words. It was interpreted in the previous chapters that the advantage occurred in bilaterally presented and highly complex stimuli by virtue of the principle of Similarity in Gestalt perception. This interpretation is further supported by the current study.

If the visual field contains repeated complex forms, there are more data points available for this kind of perceptual support. This Gestalt-like effect involves the characters falling in the foveal and parafoveal field of view, but it is a perceptual effect: the most parsimonious explanation is that the effect occurs purely at the perceptual level, rather than involving, for instance, semantic representations. An alternative, possibly contributing effect may have been the slower rise-time of the low frequency items which allowed more opportunity for facilitation to occur.

In summary, we have shown an effect of perceptual facilitation that is a stronger demonstration of similar facilitation than the classic Bilateral effect; the effect does not rely on separate hemifields, but on any occasion a substantial number of background characters will have been in the other hemifield. There is still the possibility that the background effect might have resulted from some form of parafoveal priming effect, generated by the participant viewing the background characters close to the target and processing them preattentively. The resulting orthographic, phonological and/or semantic representations would then support those of the target character, and accelerate recognition of the target. There are several arguments to make here. First, subliminal priming is not taken as an explanation of the Bilateral effect in English, although the stimuli in those experiments were of equal status, and thus perhaps more likely to encourage parafoveal processing. Secondly, Chinese characters are more visually complex than English words, and lend themselves less to parafoveal processing of a low-spatial frequency character. This view is supported by Tsai (1997), in his model simplified Chinese characters were less easily recognised than traditional Chinese in the parafovea.

Conclusion

We have seen, in previous chapters, that there is a tendency for the

Bilateral effect to occur with Chinese characters (compared with a stronger Bilateral effect in words from alphabetic languages). We have seen that this redundancy effect cannot be elicited by presenting the same character at different spatial scales. In the current chapter we have seen that a redundancy effect can be elicited more effectively with Chinese characters when there is more than just on other version of the stimulus in the vicinity of the target. This result suggests that there are cumulative aspects to the redundancy effect. In the model we have presented the processing which might have been happening in the Bilateral effect, this summation may result from the parafoveal viewing of the left half of a character which is located to the right of the target character, and the right half of a character which is located to the left of the target character. Finally, we have shown that a redundancy effect occurs in a task in which fewer assumptions are made about the directing of the participants' attention.

It is intriguing to know how the low level perception and the finegrain processing integrate as a whole in the character processing. The recognition of a Chinese character must take account of its holistic configuration and also its finegrain features such as those in strokes and phonetic/semantic radicals. In the next theme we aim to investigate the configural versus componential processing of single Chinese characters.

Theme 3. Grotesque characters

Chapter 8. The Configural Processing of Chinese Single Character

Abstract

In this chapter we examine configural processing with single Chinese characters by a series of three experiments analogous to Thatcher Illusion. The Thatcher Illusion (Thompson, 1980) demonstrates viewers' unawareness of the upright incoherent features on an inverted face. This unawareness indicates that the recognition of an inverted face has lost at least some of its global relational coding and is based focally on its components. The current chapter tests Chinese single characters with a similar manipulation of the radicals. First, global relational coding was retained and no substantial support was found for a direct analogy between the recognition of faces and Chinese characters with respect to the Thatcher Illusion. The transformations in the Chinese characters were noticed by Chinese readers, regardless of the upright or inverted orientations of the characters. Second, with equal numbers of radical types, we introduce a factor: Size of the transformation, and focus on the comparison of the stimulus types "Normal Inverted" and "Grotesque Inverted". Again, participants apparently retained configural processing, which do not represent an analogue of the Thatcher illusion. In the third experiment, we refined the methodology by restricting the radicals to be approximately symmetric in both vertical and horizontal axes (more closely analogous to the eyes and mouth in the Thatcher Illusion) and show a Symmetry effect. This paradigm shows an analogous result to the Thatcher Illusion: the transformation of the symmetric parts in characters was unnoticed. Phonetic radicals and semantic radicals are also suggested as likely to be involved with different modes of processing. In sum, this novel study of the Thatcher Illusion in Chinese characters demonstrates both broad and fine configural processing in Chinese character recognition.

(Part of this chapter has been published as Chou & Shillcock (2002d).)

8.1. Background

This chapter aims to investigate configural versus componential processing in Chinese character recognition. The motivation for this study is as follows. Weekes et al (1998), Weekes and Zhang (1998, 1999), and Zhou (1999a, b) have proposed and explored a decomposition procedure in the recognition of Chinese compound characters. However, not all researchers agree that the recognition of Chinese characters depends entirely on the basis of their parts and not their wholes. First, there is a degree of physical integration in some characters, with nesting of one radical inside the other, or the partial encircling of one radical by another. Second, all the orthographic information in different parts of a character will be perceived simultaneously or in close succession, and the brain probably cannot help but absorb the probabilities of the various combinations. Third, although Zhou (1999a, b) pointed out that to name a Chinese character requires a decomposition process of its phonetic radical from the whole character, a correct pronunciation still needs information from both the phonetic radical and the whole character. The reason, as discussed in the Introduction, is that phonetic radicals only serve as a cue to the pronunciation/name of the character. The phonological regularities vary: a phonetic complex character is not always pronounced as its phonetic radical, actually less than 40% are. Hence, Chinese readers might use holistic, configural processing as part of character recognition.

In order to investigate this issue in the processing of Chinese characters, we developed a research paradigm distinctive from traditional methods (such as the priming task) in word recognition studies. The present chapter used a different technique, drawn from the study of the Thatcher illusion in face recognition. The recognition of faces and Chinese characters both need expertise in featural detection and categorisation of the stimuli. Since Rossion,

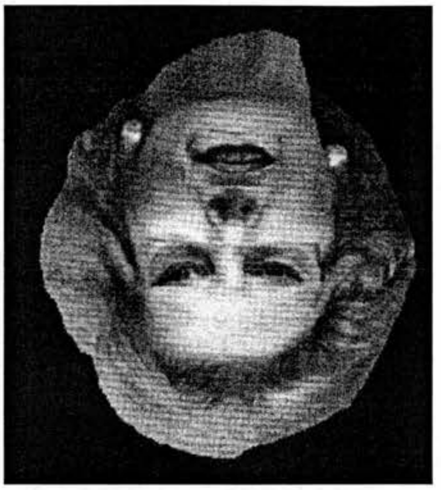


Figure 43. The grotesque-inverted face: the upright eyes and mouth look normal on an inverted face.

Joyce, Cottrell, and Tarr (2003) reported that faces, printed words, and cars presented upright or inverted all elicited at the same latency a robust N170 during an orientation decision task; additionally, the recognition of Chinese characters have been repeatedly reported to cause similar effects in the fusiform gyrus (see below), and we take these facts as supports that it is a reasonable strategy to inspect focal or holistic processing in Chinese characters using a technique drawn from face recognition research.

8.1.1. The Thatcher illusion

In 1980 Thompson named a new illusion, demonstrated with a portrait of Margaret Thatcher, the Thatcher Illusion. In this illusion, when the parts of a face are turned upside down and the whole face is itself inverted as Figure 43, viewers hardly notice a transformation in Mrs Thatcher's expression. However, if the same face is viewed after the picture is rotated to an upright position as Figure 44, it reveals that we have been cruelly deceived by the smiling Mrs Thatcher.

Figure 44. The grotesque face with the upside down eyes and mouth.

The Thatcher illusion suggests that when faces are inverted, the processing of the features in a face is preserved, but the relational coding of the parts of the face tend to be impaired. Thus the task encourages attention to components (Bartlett & Searcy, 1993). As addressed by Rakover (1999), the "external pattern" is dominant when a face is upright, whereas the "internal pattern" is dominant when a face is inverted. Reliance on the internal pattern reflects a disruption of the encoding of holistic information and configural processing, which plays a critical role in memory for faces (Leder, Candrian, Huber, & Bruce, 2001; Rhodes, Brake, & Atkinson, 1993).

Ambadar (2002), Sturzel and Spillmann (2000), and Lewis (2001) extended the study to consider the angle of rotation and demonstrated that the loss of configural processing occurs suddenly as a face is rotated slowly from upright to inverted, and the mean thresholds were found to lie between 94 degrees and 100 degrees relative to the vertical axis. Sturzel et al. suggest a neuronal step-tuning of hypothetical face cells in the human brain, underlying the configural versus componential processing of upright versus inverted faces.

8.1.2. Face recognition and the "fusiform face area"

Kanwisher, Tong, and Nakayama, (1998) used fMRI to study the effects of face inversion on the human fusiform face area, and they found that the fMRI signal intensity was reduced when faces were presented upside-down. This result indicated that inverted faces can still activate this possibly face-specific mechanism/region in the human fusiform lobe.

The human fusiform face area has been claimed to be selectively involved in the perception of faces. The strongest version of this claim has been made by Kanwisher since 1997 as she found that the human fusiform face area responded more strongly to intact and front-view faces than to scrambled faces or photos of houses (Kanwisher, McDermott, & Chun, 1997), and more strongly to human faces and human heads, compared with other stimuli like whole human or animal heads (Kanwisher, Stanley, & Harris, 1999). Like human faces, Chinese characters are overwhelmingly seen in an upright position and a very large number of times, and we may expect this fact to influence their processing in a similar way. Indeed, Chinese characters may be the stimulus more comparable to faces, compared with other stimuli that have been used to probe the fusiform gyrus.

8.1.3. The fusiform gyrus, expertise and configural processing

Several factors are believed to be involved in this face-specific activity, such as covert visual attention, which was found in the face-/house-matching versus passive central viewing (Wojciulik, Kanwisher, & Driver, 1998). Two more important factors, the levels of categorization and expertise also seem to determine the specialization of this area. Gauthier, Skudlarski, Gore and Anderson (2000) concluded that the right fusiform face area and the right occipital face area of an expert respond more intensively to a stimulus in which they had some expertise, compared with a non-expert. For instance, the fusiform gyrus of bird experts was more sensitive to birds than cars and vice versa for car experts. On the other hand, it should be borne in mind that the most sensitive changes in signal intensity still occurred for faces in the two groups of experts. It was interpreted by Gauthier et al. that experts may use a more configural strategy to identify objects in which they have expertise and may be able to do the task automatically, whereas non-experts may rely more on a featural strategy. Perhaps only configural processing is a good predictor of behavioural expertise.

8.1.4. The fusiform gyrus and Chinese character recognition

More recently, Lee (2001) used fMRI studies to demonstrate the neural basis of the recognition of Chinese characters. She indicated that the activation of the left fusiform gyrus is related to Chinese orthography-phonology transformations. Kuo (2001) also shows that Chinese word reading intensively activates areas including the left fusiform gyrus, the inferior occipital gyrus, the left inferior frontal gyrus, the superior and inferior parietal lobules, etc, and the cortical structures for phonological processing in homophone judgments activates the middle to inferior occipital gyri including the fusiform and the lingual gyri.

Although it is initially surprising that the face-specific area was activated not only in the face recognition process but also in the Chinese orthography-phonology transformation and Chinese phonological processing, further consideration shows substantial similarities between the two tasks: both involve distinguishing one member of a set from the rest of the set, where all the members of the set are very similar in many respects. Accordingly, we conducted a series of experiments to replicate the Thatcher illusion by using Chinese characters to inspect configural versus componential aspects of character processing. We hypothesized that there would be an analogous illusion with Chinese characters. Such an illusion with Chinese characters would

Figure 45. Four stimulus-types of Thatcher's portrait.

demonstrate a particular type of configural processing in character recognition.

8.1.5. Methodology: Grotesqueness rating of faces

The methodology we used was similar to Bartlett and Searcy (1993), in which they ask participants to rate each face for "grotesqueness" using a seven-point scale (point 1, least grotesque, and point 7, most grotesque). In their experiment, the first group of participants viewed four stimuli consisting of the Figure 44 version (Thatcherized face, an upright face with inverted eyes and mouth) and three expression conditions: smiling-, neutral-, and grotesque-expression. The second group of participants viewed the Figure 44 version and a distorted face; both of them were presented twice, one in upright position and the other inverted. The first group tested whether the illusion resulted from the expression or the Thatcherized transformation of the face. The result showed that the upright grotesque-expression faces received lower grotesqueness ratings than the upright-Thatcherized faces. The expression hypothesis was firmly rejected. It was not the expression that made a face look grotesque. The critical finding of the second group was that the inversion effect was greater for Thatcherized faces than for distorted faces, and that the inversion impairs the holistic encoding of the Thatcherized faces.

As Chen, Allport and Marshall (1996) reported, the stroke patterns are the basic perceptual units in a character and is more crucial than the number of strokes in word recognition. Thus controlling the number of stroke pattern/radicals is more essential than controlling the number of strokes. The materials we used in a series of studies were single Chinese characters comprising four portions of radicals. Radicals in single characters were treated and transformed in this experiment like the parts of a face. Chinese readers in this study were asked to record their judgements on a scale, according to how grotesque they felt the characters looked in different upright and inverted orientations. We further investigated the radical effect by carrying out transformations on three types of radicals: phonetic, semantic or non-crucial radicals.

8.2. Experiment 7-1. Grotesque characters

8.2.1. Hypothesis

Although Chinese characters may be recognized in terms of their components, we hypothesize that there is also low-level, configural, integrated, global processing of each character. In this experiment we inverted a radical in a Chinese character, analogous to the eyes or mouth being changed in the Thatcher illusion, and then turned the whole character upside-down, as shown in Figure 45. If participants had the analogue of the Thatcher illusion for Chinese characters – they were unaware of the incoherence of the inverted radicals – then this condition, "Grotesque Inverted", would be seen as being as normal as the "Normal Inverted" condition. In this case we could say that the recognition of an inverted character has lost at least some of its global relational coding and is based focally on its components.

8.2.2. Participants

Twenty-five Taiwanese undergraduate and postgraduate students participated in the experiment. All of them were native speakers of Mandarin

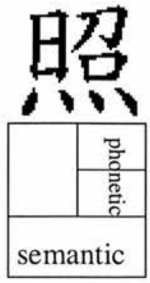


Figure 46. An example of a four-portion Chinese character 照 (jao4) (meaning "shine on").

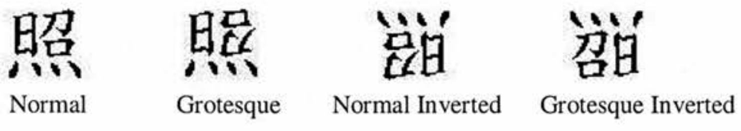


Figure 47. Four stimulus-types of the character 照.

and fluent in English with normal or fully corrected vision. Eleven participants were males and fourteen females.

8.2.3. Stimuli

Thirty-three four-portion Chinese characters were chosen from the Wen-Xing modern Chinese dictionary (1987). All of them were made of four pronounceable radicals. An example of the composition of a character is presented in Figure 46. Three types of radical within the characters were used: phonetic radicals, semantic radicals and non-crucial radicals (i.e. neither phonetic nor semantic radicals). Each character was presented in four stimulus-types: Normal (an upright orientation), normal inverted, grotesque (characters with one radical inverted), and grotesque inverted (characters with one radical inverted and the whole character inverted again), as shown in Figure 47. The inversion happened in semantic radicals for 14 characters, phonetic radicals for 5 characters and non-crucial radicals for 14 characters, constrained by the availability of appropriate characters in the lexicon. Experimental materials were printed individually on A4 paper, approximately 3.0 cm in width and 3.0 cm in height with a five-point scale for recording the participants' response on each page. Materials and questionnaires are listed in Appendix 5.

8.2.4. Procedure

The Experiment was based on a 3 by 4 (types of radicals by stimulus-type) between-participant design. Each participant scored each of the 33 characters in only one of the four stimulus-types. Four sets of stimulus materials were constructed in which stimulus-type was randomly assigned to the characters, but ensuring that the characters received, as far as possible, equal numbers of each stimulus-type. In other words, each participant saw all thirty-three characters, and each character once only. Participants were instructed to make a quick judgement about how grotesque the character was by marking a five-point scale. Point five stands for the most grotesque appearance and point one for the most normal appearance. In the instructions, participants were told not to attempt any mental rotation of any of the stimuli, but to make an initial judgement that abstracted away from the fact that some of the stimuli were inverted.

8.2.5. Analysis and results

Significant Stimulus-type effect

During the experiment, our participants did not report any difficulties that stopped them being able to judge inverted characters or normal ones. A Friedman analysis by ranks was carried out by SPSS with two within-participant variables: 3 levels of Radical and 4 levels of Stimulus-type. The results are presented in Tables 34 to 37 and Figures 48 and 49. It showed a significant stimulus-type effect (N=32, Chi-Square= 83.39, $p < .01$). A post-hoc test was carried out using the equation shown in Table 37 (Wang et al., 1999), in which

Table 34. Descriptive statistics of Experiment 7-1.

Radical	Stimulus-type	Mean Score	S.E. of Mean
Non-crucial	N	1.31	.12
	G	4.07	.12
	NI	2.12	.22
	GI	3.57	.20
Phonetic	N	1.13	.13
	G	3.92	.39
	NI	2.29	.17
	GI	3.45	.54
Semantic	N	1.05	.003
	G	4.13	.11
	NI	2.12	.18
	GI	4.17	.15

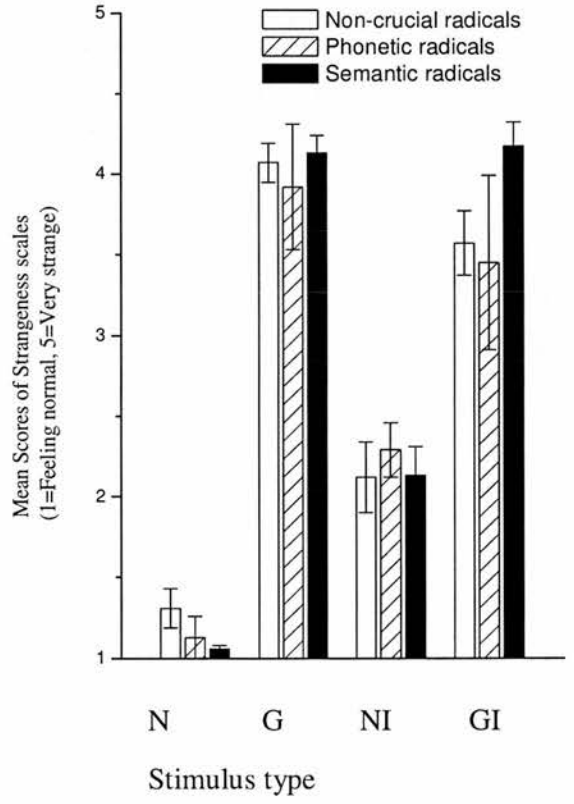


Figure 48. Significant main effect of Stimulus-type in Experiment 7-1.

Table 35. Mean score and mean rank of the four stimulus-types on Grotesqueness Scale in Experiment 7-1.

Stimulus-type	Mean Score	Mean Rank
Normal	1.18	1.06
Grotesque	4.08	3.67
Normal Inverted	2.15	1.98
Grotesque Inverted	3.81	3.28

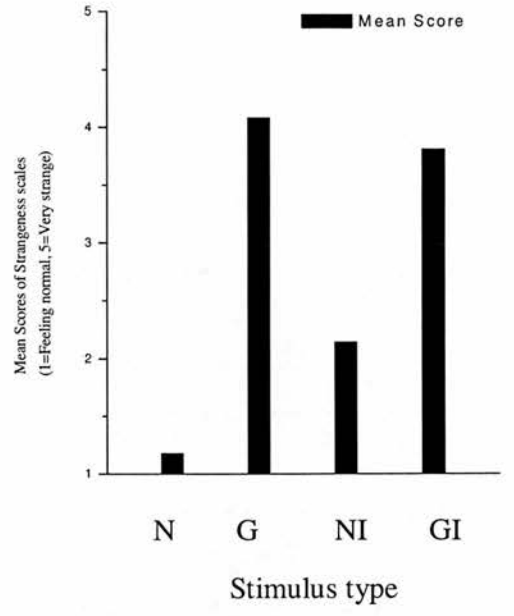
the pair-comparison would be significant only when the Difference of Rankings > .57. The post-hoc test showed a significant difference between every two stimulus-types except between Grotesque and Grotesque-Inverted. The radical effect is presented with respect to the different radical types in the following section (see Figure 48).

Semantic radicals

As shown in Figure 48, the differences between the radicals were more distinct in the Grotesque-Inverted than in the other stimulus-types. Indeed, there is a marginally significant ($.05 < p < .1$) radical effect in the Grotesque-Inverted stimulus-type. Furthermore in the post-hoc tests, in the Grotesque-Inverted stimulus-type semantic radicals scored higher on the Grotesqueness Scale than both phonetic and non-crucial radicals.

Phonetic radicals

A clear analogy with the Thatcher illusion in Chinese characters would show equal grotesqueness ratings for Grotesque-Inverted and Normal-Inverted stimulus-types. The characters with phonetic radicals tended to match this assumption: the participants gave closer grotesqueness judgements for the Grotesque-Inverted and the Normal-Inverted stimulus-types, compared with the other radical types; the difference between the Grotesque-Inverted and the



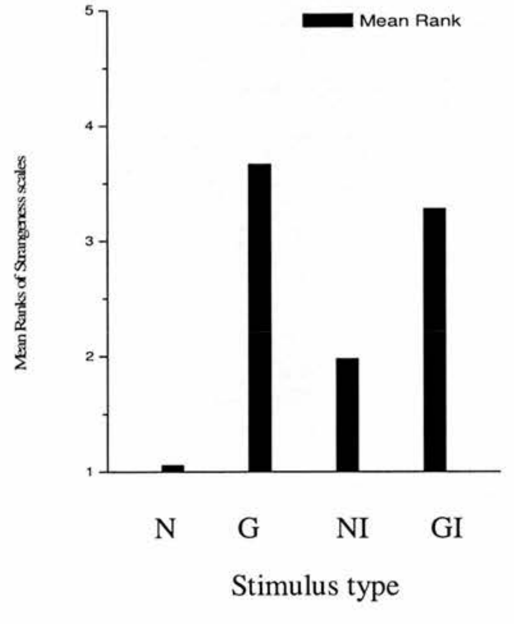


Figure 49. Mean score and mean rank of the four stimulus-types on Grotesqueness Scale in Experiment 7-1.

Table 36. Statistics of Friedman test in Experiment 7-1.

N	32
Chi-Square	83.39
df	3
Asymp. Sig.	.00

Table 37. The post-hoc test of Stimulus-type effect in Experiment 7-1. (Pair-comparison is significant only when the Difference of Rankings > .57)[1]

Difference of rankings	N	G	NI	GI
	1.06	1.98	3.67	3.28
N 1.06	--	0.92*	2.61*	2.22*
G 1.98		--	1.69*	1.30*
NI 3.67			--	0.39
GI 3.28				--

Normal-Inverted phonetic types was non-significant (p= .13). This means that an inverted phonetic radical in the Grotesque-Inverted format tended to be difficult to spot; i.e., it tended to be seen as being as normal as that in the Normal-Inverted version. However, note that in this experiment there were only five characters in which a phonetic radical was changed.

[1] Equation of post-hoc test for Friedman analysis: When α= .05, κ= 4 (k: the number of levels of the factor), then $(\alpha/\kappa)(\kappa-1)$= (.05/4)(4-1)= .0375. When p= .0375, Z= 1.78. $Z^*\sqrt{(4(4+1)/(6*32))}$= 0.57. The pair-comparison is significant only when difference of two ranks is larger than 0.57.

8.2.6. Discussion and conclusion

Stimulus-type effect

The hypothesis of this experiment was taken from the Thatcher Illusion: people did not recognise the erratically oriented eyes in the inverted face. Thompson's experiment demonstrated that when the face was inverted face recognition processing lost the configural relationships between the facial features, which therefore tended to be processed componentially. The processing of more global information about the face was disrupted.

However, in the current study Chinese characters did not show such clear componential processing during recognition of inverted characters. All of the semantic, phonetic and non-crucial radicals were spotted as grotesque when they were incoherent with the whole character, given that the Grotesqueness scores for Grotesque and Grotesque-Inverted were higher than those for Normal and Normal-Inverted. More specifically, the difference between the Stimulus-types for Grotesque and Grotesque-Inverted was not significant, and that between Normal-Inverted and Grotesque-Inverted was significant. The Grotesque-Inverted characters were seen as being as odd as Grotesque characters, meaning that the incoherence of the Grotesque-Inverted characters was effortlessly perceived once the character was changed; character recognition was disrupted. This result could indicate that global processing was happening, even when the characters were inverted, where the global information is most likely to be disrupted.

Semantic radicals

There was still an opportunity to suggest a componential process in Chinese character recognition. As shown in Figure 48, the effects on the radicals were more divergent in the Grotesque-Inverted stimulus-type. The semantic radicals in this stimulus-type were scored higher than the two other radicals, on the grotesqueness scale. This indicated that the Semantic radicals were more likely to be spotted when they were transformed, and implied that different types of radicals may be weighted unequally during character recognition.

Phonetic radicals

As shown in Figure 48, phonetic radicals had the smallest difference between the stimulus-types Normal-Inverted and Grotesque-Inverted, compared with the other kinds of radicals. This result showed that participants may be less able to spot changes in phonetic radicals compared with the other two kinds of radicals in an inverted character, when the relationships to other parts of the character were disrupted. This revealed another aspect to the global processing hypothesis of character recognition.

Modifications for the next experiment

This experiment so far provided no substantial support for the hypothesized change to componential processing brought about by inversion of the stimulus, in Chinese character recognition. On the other hand, as this experiment was the first experiment with a limited number of four-portion characters, the numbers of radicals in each kind were not perfectly matched. To compensate for this weakness, we conducted a further experiment aiming to equalize the number of characters for each type of radical with a larger corpus and to emphasise the stimulus-types Normal-Inverted and Grotesque-Inverted. This modified experiment is presented next.

Conclusion

To sum up, the results of the current experiment provided no substantial support for a direct analogy between the recognition of faces and Chinese characters with respect to the Thatcher Illusion. However, we found that changes to the Semantic radical tended to be more easily spotted than changes to the other two radicals and that, if anything, the Phonetic radicals performed more like the eyes and the mouth in the Thatcher Illusion, compared to other radical types. In the following experiment we adjust the number of radicals and focus on the comparison on Normal Inverted and Grotesque-Inverted stimulus-types for a detailed exploration of the phenomenon.

8.3. Experiment 7-2. Grotesque characters

As we saw in the Experiment 7-1, the result did not clearly support the hypothesis of focal processing in inverted Chinese character recognition. To further distinguish the potential difference between the phonetic radicals, semantic radicals and other non-crucial radicals, we conducted the current experiment with more character stimuli from a larger corpus. Additionally, we added a new variable, Size of transformation/changes, to control the portions changed within single characters. This kind of preattentive factor was crucial in the capture of attention (as reviewed in Experiment 6, the Overlap experiment). Thirdly, we extracted only two Stimulus-types from the previous experiment for comparison: the Normal Inverted and the Grotesque Inverted. A significant difference between them would indicate no analogy with the Thatcher Illusion and would support the global processing hypothesis, that large-scale configural processing was happening in the inverted versions. No significant difference between them would indicate an analogy with the Thatcher illusion and suggest that large-scale configural processing had been lost in inversion and the participants were relying on the processing of the component parts of the characters.

8.3.1. Hypothesis

We distinguish a Configural Processing Hypothesis from a Componential

Figure 50. An example of a character with a small radical changed, upper: non-character, lower: real character.

Figure 51. An example of a character with a large radical changed, upper: non-character, lower: real character.

Processing Hypothesis. The former states that some degree of larger-scale configural processing normally occurs during Chinese character recognition, and the later states that no larger-scale configural processing occurs. Thus, if the difference between the Grotesqueness scores for Grotesque Inverted and Normal Inverted reach significance, the experiment will not resemble the Thatcher illusion and it will support the Configural Processing Hypothesis; failure to find a significant difference will lead us to accept the Componential Processing Hypothesis.

8.3.2. Participants

Twenty male and twenty female native Chinese speakers participated in this study. All of them had normal or fully corrected vision and had learned to read Chinese script for at least ten years.

8.3.3. Stimuli

The design was similar to Experiment 7-1, except that we used more characters with inverted phonetic radicals to equalize the number of characters for each radical condition. A variable, Size of changes, was added to this experiment to represent the size of the parts inverted when the whole character was changed to the Grotesque form (Figures 50 and 51). Only one radical was inverted for each character and the Size was either large or small. To control complexity, we used four-portion characters comprising four separate radicals. A large radical is the one occupying more than a quarter of the size of the character, while a small radical is the one occupying less than a quarter. This experiment contained two Stimulus-types: Normal Inverted and Grotesque Inverted. The Grotesque Inverted Stimulus-type was made by inverting one of the radicals of a character and then inverting the whole character again. The same procedure was done for the phonetic, semantic and non-crucial radicals. The Normal Inverted Stimulus-type was an unchanged, normally written character, which was then turned upside down. All the characters were printed on A4 paper, approximately 3.0 cm width and 3.0 cm height with a five-point Grotesqueness Scale on each page (as attached in Appendix 5). In each Stimulus-type, there were 30 characters, 10 for each kind of radical. Among the 10 characters, 5 of them were large radicals, which occupied more than one-third of the space in a character, and the other 5 were small radicals, which occupied less than one-third of the space in a character.

8.3.4. Procedure

First, each participant was instructed to name each character, which was presented individually. Then, they had to mark a score on the five-point scale concerning how grotesque they felt the characters looked according to their first impression and without mental rotation of the characters. Each participant saw 60 characters in total, half Normal Inverted and half Grotesque Inverted Stimulus-type.

8.3.5. Result and analysis

A Friedman analyses was carried out for this experiment with three within-participant variables: Stimulus-type (Normal Inverted and Grotesque Inverted), Radical (Semantic, Phonetic and Non-crucial), and Size of transformation/changes (Large and Small) Results are presented in Tables 38 to 41 and Figures 52 to 54. The Friedman test analysed the scores by the ranks of each stimulus-type. It showed a significant Stimulus-type effect (N= 38, Chi-Square= 26.95, df = 1, $p < .001$), a non-significant effect of Size of transformation/changes (N= 38, Chi-Square= 2.19, df =1, $p > .1$) and a non-significant Radical effect (N= 38, Chi-Square= .29, df = 2, $p > .1$). A secondary test of the interaction between Size and Stimulus-type is presented under the Size effect section.

Stimulus-type effect

As shown in Figures 52 and 53, the difference of Stimulus-types was in the direction that the Grotesque Inverted characters were marked more grotesque than the Normal Inverted characters. As shown in Figure 54, the Stimulus-type effect was still significant in both sizes, given that the overall scores of Grotesque Inverted characters were larger than those of Normal Inverted. The only occasion where Grotesque Inverted characters might be seen as being as normal as Normal Inverted characters was the Non-crucial radicals in the Small transformation group, although according to a secondary test, the Grotesqueness scores between Grotesque Inverted and Normal Inverted were significantly different from each other (N = 38, Chinese-square = 8.53, $df = 1$, $p < .01$).

The Size effect

The Size effect was not significant. As Figure 54 shows, there was a tendency showing that the larger the changes in a single character in Grotesque Inverted version, the more grotesque the participants felt it looked. Small changes within a character might have less effect during the character recognition process. In a secondary analysis of the interaction of Size and Radical, the size effect was significant for Non-crucial radicals, non-significant for Phonetic radicals (N = 38, Chinese-square = .76, $df = 1$, $p > .1$), and for semantic radicals (N = 38, Chinese-square = .11, $df = 1$, $p > .1$). This effect indicates the relative importance of the semantic and phonetic radicals in processing: if only a small change occurred in the non-crucial radical it had no effect.

Radical effect

The Radical effect was not significant, as shown in Figure 52, the three kinds of Radicals performed evenly in all the conditions. According to the secondary analysis, and as shown in Figure 54, in the Large size group the

Table 38. Mean score and mean rank of the four stimulus-types on Grotesqueness Scale in Experiment 7-2.

Radical	Stimulus-type	Mean Score	S.E. of Mean
Non-crucial	NI	1.83	.15
	GI	3.14	.13
Phonetic	NI	1.78	.12
	GI	3.22	.21
Semantic	NI	1.77	.14
	GI	3.22	.18

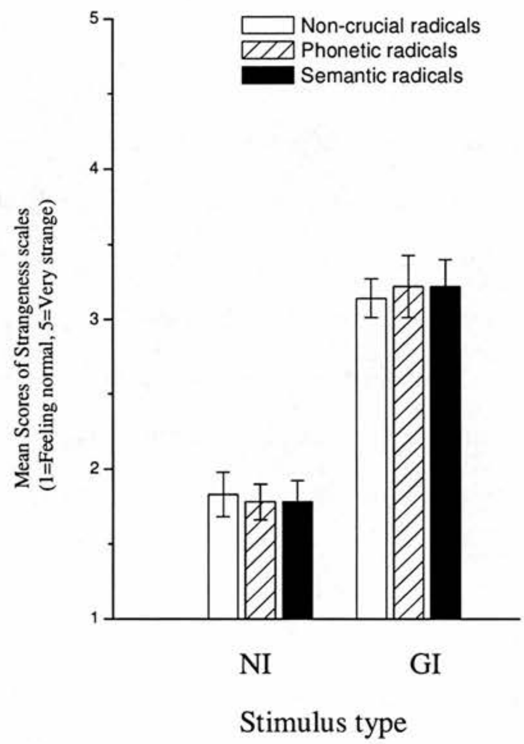
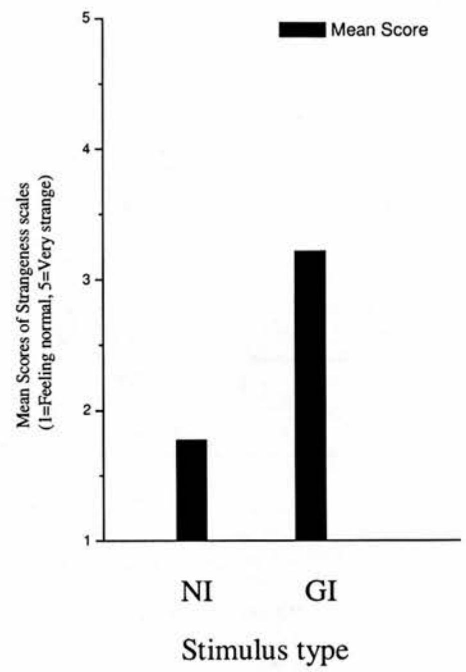


Figure 52. The overall result of Experiment 7-2.



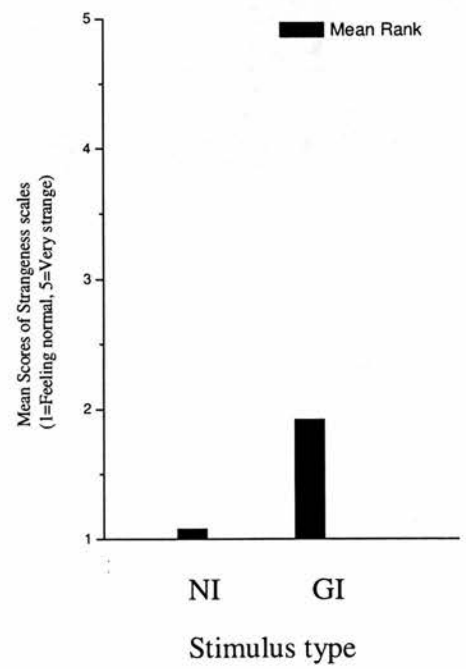


Figure 53. Mean score and mean rank of the four stimulus-types on Grotesqueness Scale in Experiment 7-2.

Table 39. Mean score and mean rank of the two stimulus-types on the Grotesqueness Scale in Experiment 7-2.

Stimulus-type	Mean Score	Mean Rank
NI	1.77	1.08
GI	3.22	1.92

Table 40. Statistics of Friedman test in Experiment 7-2.

N	38
Chi-Square	26.95
df	1
Asym. Sig.	.00

Table 41. Results of Experiment 7-2 presented by variables of Stimulus-type, Size of Inversion and Radical.

	Size	Large Inversion		Small Inversion	
Radical	Stimulus-type	Mean score	S.E.	Mean score	S.E.
Non-crucial	NI	1.72	0.15	1.93	0.17
	GI	1.59	0.13	2.46	0.18
Phonetic	NI	1.63	0.15	1.98	0.17
	GI	3.83	0.17	3.29	0.23
Semantic	NI	3.15	0.22	1.90	0.17
	GI	3.41	0.24	3.03	0.19

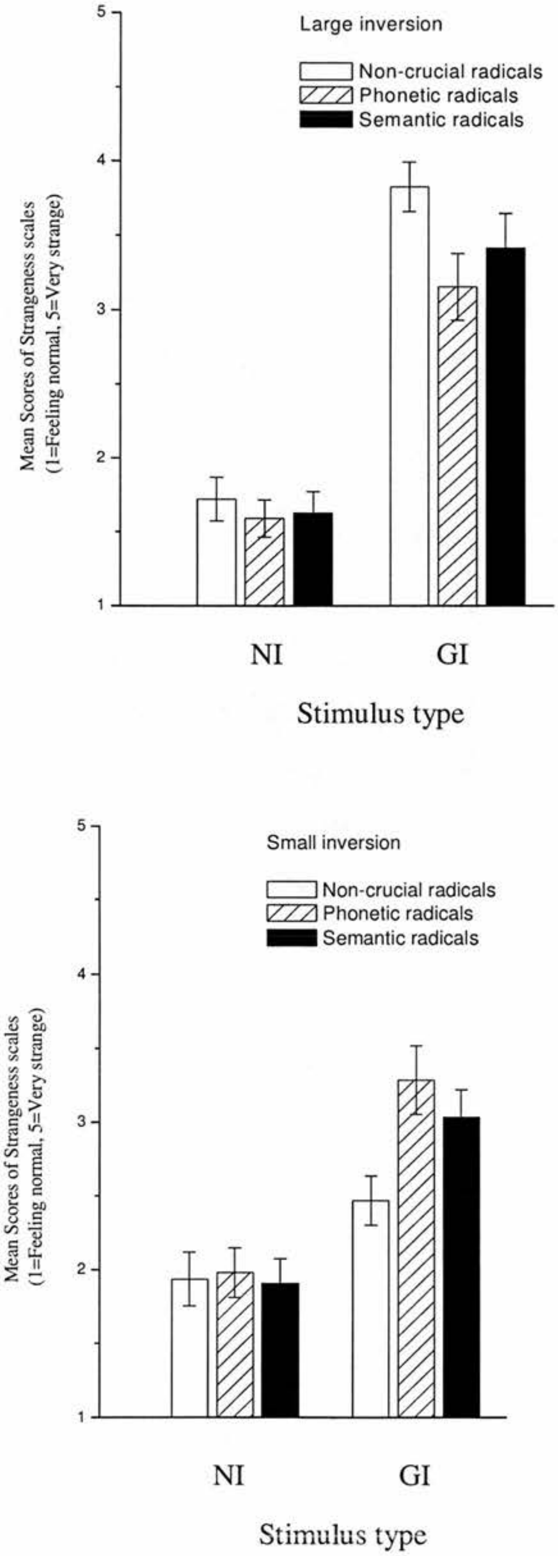


Figure 54. Results divided by Size, Experiment 6-2

Non-crucial radicals were marked more grotesque than the Semantic and the Phonetic radicals, whereas in the Small size group, the Non-crucial radicals were less strange-looking than both Semantic and Phonetic radicals.

8.3.6. Discussion and conclusion

Researchers have hypothesized that Chinese characters are recognized focally and independently in terms of their components (see, e.g., Spinks et al., 2000; Weekes et al., 1998; Ziegler et al., 2000). The results of the current study have not given unanimous support to this claim; neither have they indicated that Chinese character recognition is comparable to face recognition, with respect to the Thatcher Illusion. This experiment compared two stimulus-types - Normal Inverted and Grotesque Inverted - when the phonetic radicals, the semantic radicals and the non-crucial radicals within single Chinese characters were manipulated by two levels of Size: large and small. We have showed a significant Stimulus-type difference between the Grotesque scores for Grotesque Inverted and Normal Inverted. The experiment falsifies the analogy of the Thatcher illusion to Chinese characters and supports the retention of Configural Processing in inverted characters.

This absence of a significant Radical effect offers no support for the hypothesis that Chinese character recognition is based focally on a particular kind of radical, such as the phonetic radical.

The Size effect in non-crucial radicals reminds us of the importance of physical factors in capturing attention (as discussed in Section 6.1.4.). That is, when a large radical was inverted, it was easier to notice than when the size was small. Characters with small changes performed more like the face in the Thatcher illusion. This interpretation suggests that the illusion was to some extent related/caused by the small size of the transformation carried out on the radicals, and made them difficult to detect. This is more likely a spatial/perceptual issue rather than an issue of radical types.

Another spatial issue concerns the shape of transformation: the eyes and mouth in the Thatcher face have an approximate symmetry about a horizontal and a vertical axis. Among the characters used in the current experiment, some radicals were symmetric about a vertical axis, which might make their inversion relatively hard to detect. Thus we hypothesized that this kind of physical symmetry might be a factor causing readers' unawareness of the Radical changes. In the next experiment we control these factors.

8.4. Experiment 7-3. Grotesque characters

According to the results of the previous two experiments, an analogue of the Thatcher Illusion did not robustly occur in the recognition of Chinese characters, as the characters with inverted radicals (Grotesque Inverted Stimulus-type) were not judged as being as normal as the normal inverted characters (Normal Inverted Stimulus-type). There is a possibility that the physical shape of the element being inverted might have contributed to the illusion. As the eyes and mouth on a face are approximately symmetric both vertically and horizontally, the radicals in the characters we changed were not as symmetric in the word shape. If relative symmetry were a factor, then participants should not notice the inversion of a relatively symmetric radical that was embedded in an inverted character. This experiment aims to examine this hypothesis.

8.4.1. Hypothesis

We hypothesised that people would not be aware of an approximately vertically and horizontally symmetric radical as being changed, when it was contained in a character and the whole character was inverted. These conditions represent the purest analogy with the Thatcher Illusion.

8.4.2. Participants

Twenty Taiwanese males participated in this experiment. All of them were skilled Chinese readers with normal or fully corrected vision.

8.4.3. Stimuli

The stimuli of this experiment were twelve Chinese characters with individually transformed radicals. The physical shapes of these radicals were in one of the three between-item conditions: relatively symmetric in both vertical and horizontal axes (such as 口), relatively symmetric in a vertical axis only (such as 皿), or asymmetric on both axes (such as 儿). This was called the Symmetry factor. Four levels of the second factor, Stimulus-type, were used within-item as in Experiment 7-1: they are Normal, Normal Inverted, Grotesque and Grotesque Inverted. So that we had 48 stimuli with a Grotesqueness scale ready to be judged by participants. When we further divided the characters by their radical types, seven of the characters had inversion in their phonetic radicals and five of them in the semantic radicals. The number of stimuli was constrained by the lexicon of Chinese, which did not allow us to manipulate radical type in a perfectly controlled way.

8.4.4. Procedure

Participants viewed single characters in different conditions on an A4 paper. After a quick look for less than 1 second, they were asked to judge the characters on a Grotesqueness Scale to indicate how grotesque they felt the characters looked. The Grotesqueness Scale was a five-point scale in which Point five stands for Very Grotesque and Point one stands for Not Grotesque.

8.4.5. Analysis and Results

During the experiment, our participants did not report any difficulties that stopped them being able to judge inverted characters or normal ones. A Friedman analysis by ranks was carried out by SPSS with two within-participant

Table 42. Mean score and mean rank of the four levels of Stimulus-type in Experiment 7-3.

Stimulus-type	Mean Score	Mean Rank
N	1.13	1.57
G	4.75	3.73
NI	1.19	1.63
GI	3.47	3.07

Table 43. Mean score and mean rank of the three levels of Symmetry in Experiment 7-3.

Symmetry	Mean Score	Mean Rank
Vertical and horizontal	2.08	1.00
Vertical	2.86	2.45
Non-symmetric	2.95	2.55

variables: three levels of Symmetry and four levels of Stimulus-type. The overall results are shown in Tables 42 to 48 and Figures 55 to 57. Main effects of Symmetry and Stimulus-type were both significant. Symmetry effect: N=10, Chi-Square= 15.44, *df*=2, $p< .001$; Stimulus-type: N=30, Chi-Square= 73.95, *df*=3, $p< .001$. A post-hoc test was carried out using the equation shown in Tables 44 and 45 (Wang et al., 1999), in which the pair-comparison would be significant only when the Difference of Rankings > .59 for the Stimulus-type and >.82 for the Symmetry. Scores of individual symmetry conditions are shown in Figures 55. The upper graph in Figure 55 shows that the Stimulus-type was significantly different for any two pairs except for that between N and NI. The approximately vertically and horizontally symmetric characters match the Thatcher Illusion (Figure 55 upper graph). Characters with alterations in the radicals symmetric in a vertical axis did not support our hypothesis (Figure 55 lower-left graph). Characters with non-symmetric radicals did not resemble

Table 44. Post-hoc test of Stimulus-type effect in Experiment 7-3. (Pair-comparison is significant only when the Difference of Rankings > 0.59)[2]

Difference of rankings	N 1.57	G 3.73	NI 1.63	GI 3.07
N 1.57	--	2.16*	0.06	1.50*
G 3.73		--	2.10*	0.66*
NI 1.63			--	1.44*
GI 3.07				--

Table 45. Post-hoc test of Symmetry effect in Experiment 7-3. (Pair-comparison is significant only when the Difference of Rankings > .82)[3]

Difference of rankings of Symmetry	Vertical and horizontal 1.00	Vertical 2.45	Asymmetry 2.55
Vertical and horizontal 1.00	--	1.45*	1.55*
Vertical 2.45		--	0.10
Asymmetry 2.55			--

faces in the Thatcher illusion (Figure 55 lower-right graph).

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[2] Equation of post-hoc test for Friedman analysis: When α= .05, κ= 4 (k: the number of levels of the factor), then $(\alpha/\kappa)(\kappa-1)$= (.05/4)(4-1)= .0375. When p= .0375, Z= 1.78. $Z^*\sqrt{}(\kappa(\kappa+1)/(6^*N))$=1.78*$\sqrt{}$(4(4+1)/(6*30))= 0.59. The pair-comparison is significant only when difference of two ranks is larger than 0.57 in the *Stimulus-type*.

[3] Similarly, in the *Symmetry* factor, α= .05, κ= 3 (k: the number of levels of the factor), then $(\alpha/\kappa)(\kappa-1)$= (.05/3)(3-1)= .0333. When p= .033, Z= 1.84. $Z^*\sqrt{}(\kappa(\kappa+1)/(6^*N))$=1.84*$\sqrt{}$(3(3+1)/(6*10))= 0.82. The pair-comparison should be larger than 0.82 to reach significance of post-hoc tests.

Table 46. Mean score and Standard Error of Mean for four levels of Stimulus-type and three levels of Symmetry in Experiment 7-3.

Symmetry along axis	Stimulus-type	Mean Score	S.E. of Mean
Vertical and Horizontal	N	1.10	.04
	G	4.74	.11
	NI	1.11	.05
	GI	1.33	.01
Vertical	N	1.20	.13
	G	4.80	.13
	NI	1.25	.13
	GI	4.30	.20
Asymmetric	N	1.10	.01
	G	4.70	.15
	NI	1.20	.13
	GI	4.80	.13

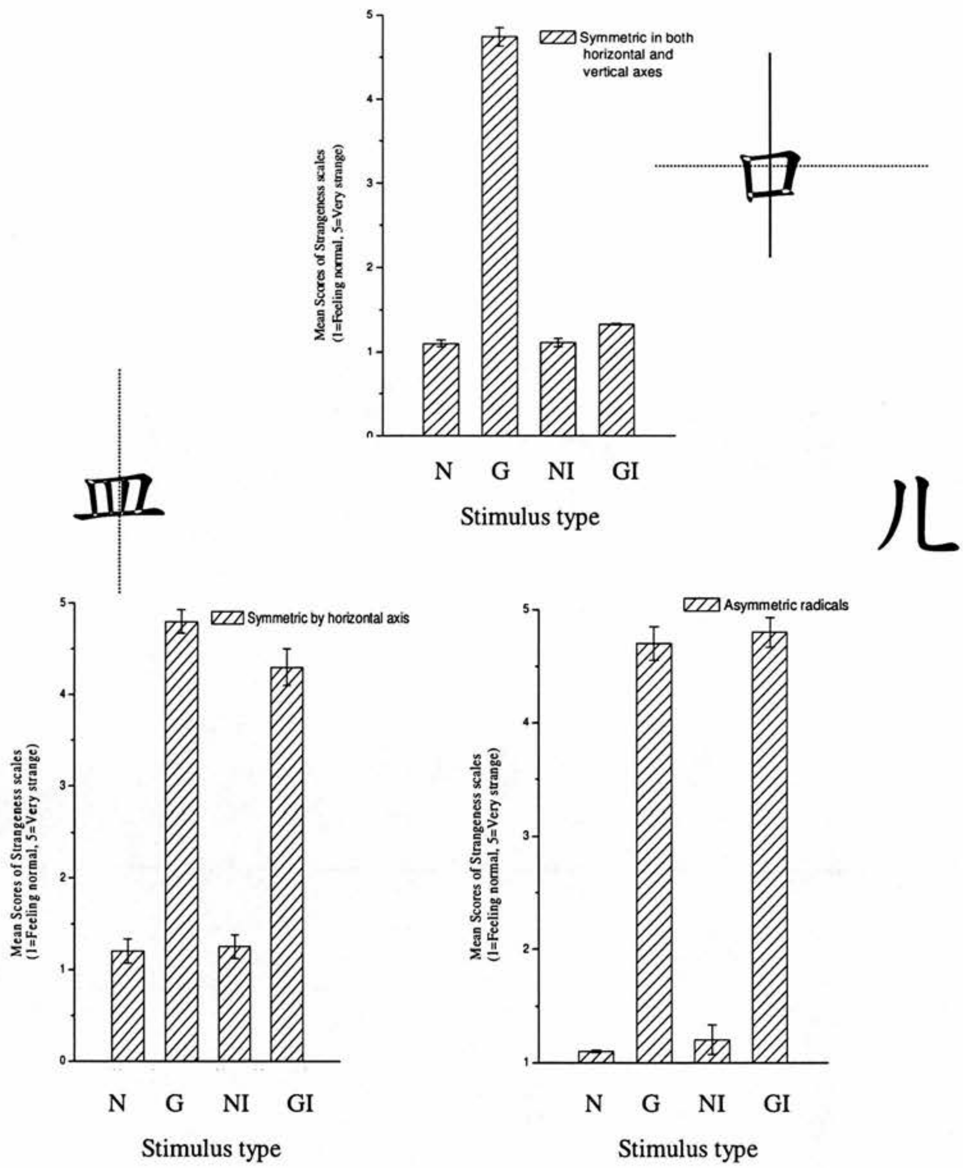

Figure 55. Overall results of Grotesque characters 7-3.

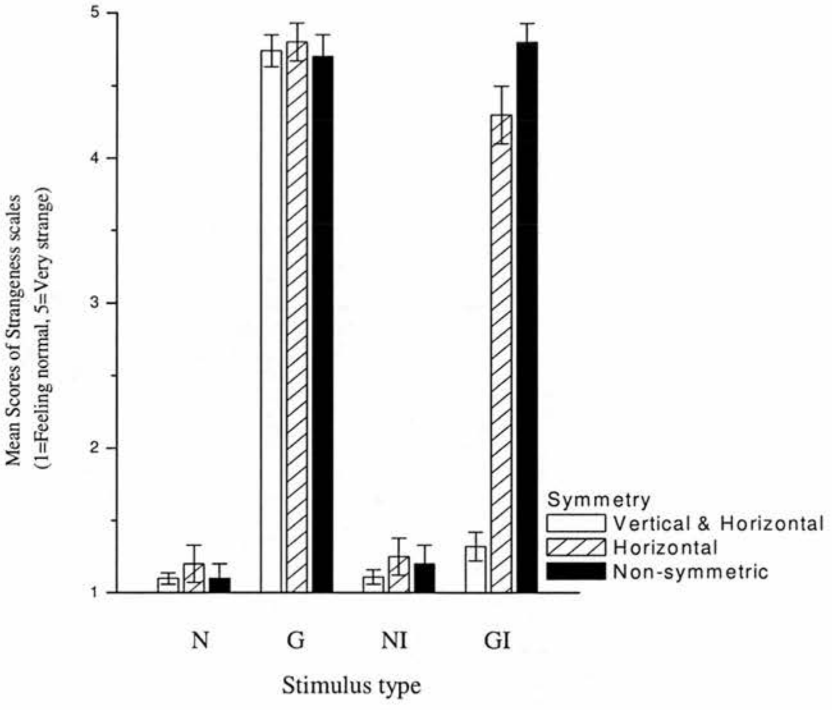

Figure 56. Overall results presented according to Symmetry and Stimulus-type.

Radical effect

Although the number of characters comprising semantic and phonetic radicals were constrained by the Chinese lexicon and not perfectly matched in each symmetry condition, we still analysed the data with respect to the more conservative claim in the following text, Tables 47 and 48 and Figure 57. By separating the results according to radical type, we noticed that phonetic and semantic radicals had the greatest difference in the Grotesque Inverted stimulus-type: phonetic radicals tended to make the Grotesque Inverted stimulus-type be seen as being as normal as the Normal Inverted stimulus-type. However, the characters comprising semantic radicals performed differently with respect to the stimulus types (see Figure 57). Using a nonparametric Mann-Whitney and Wilcoxon test we found that the radical difference in each

Table 47. Mean score and mean rank of the four stimulus-types on Grotesqueness Scale in Experiment 7-3.

Radical	Stimulus-type	Mean Score	S.E. of Mean
Phonetic	N	1.07	.10
	G	4.78	.94
	NI	1.07	.08
	GI	2.65	.15
Semantic	N	1.10	.09
	G	4.70	.08
	NI	1.17	.07
	GI	3.53	.13

stimulus-type condition was not significant except for that in the GI condition.

This difference suggests that radicals of different kinds might trigger different modes of processing. A semantic radical might be processed with more weight given to its global relationship to other parts of the character, compared with a phonetic radical. Thus when the semantic radicals were inverted, the inversion was easily to spot, and had high scores in the Grotesqueness scale. In contrast, a phonetic radical is normally a pronounceable unit or an integrated character itself. It is therefore reasonable to interpret that the recognition of a phonetic radical needs less global information from the whole character. If this claim were true, it would support the focal processing of phonetic radicals in the recognition of Chinese characters.

Table 48. Nonparametric Mann-Whitney and Wilcoxon test examining simple Radical effect in Stimulus-type.

Stimulus-type	N	NI	G	GI
Mann-Whitney U	17.50	11.50	12.50	2.50
Wilcoxon W	32.50	39.50	27.50	30.50
Z	.00	-1.05	-.97	-2.46
Asymp. Sig. (2-tailed)	1.00	.29	.33	.01*
Exact Sig. [2*(1-tailed Sig.)]	1.00	.34	.43	.01*

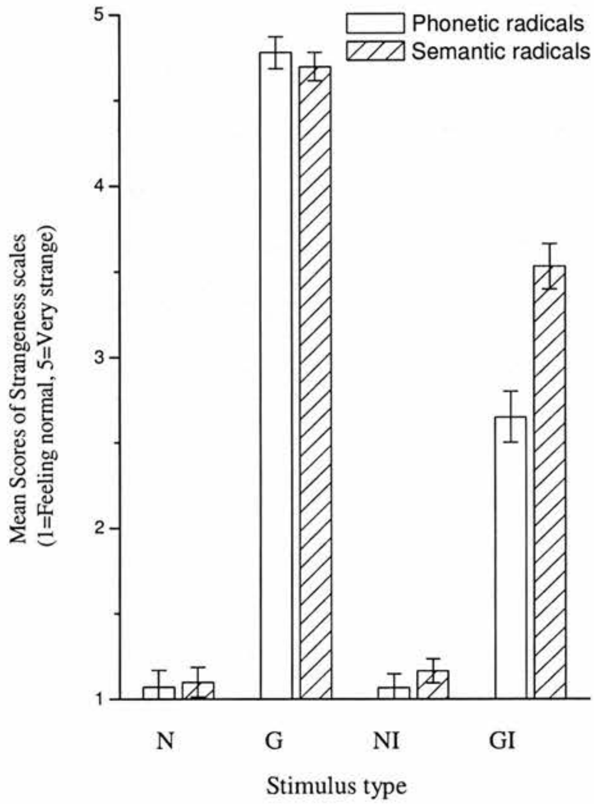

Figure 57. Results divided by radicals, Experiment 7-3.

8.4.6. Discussion

The results of the third experiment in this theme showed a loss of configural processing: the symmetric radical was spotted significantly less often, and thus had less effect on participants' perception of the character when the whole character was inverted, compared with the normal-inverted stimulus type, analogous to the Thatcher illusion. This effect was not "complete", however, as the stimuli in the Grotesque-inverted condition were still judged to be significantly more strange than those in the Normal condition; the fourth set of columns in Figure 56 were intermediate in height between those representing the grotesqueness judgements for the Normal-inverted and the Grotesque conditions. Looking at Figure 55, we see that the division into different symmetry conditions makes the interpretation clearer: the stimuli which were symmetric on both dimensions gave a pure analogy with the Thatcher Illusion, whereas the other two symmetry conditions did not. As Figure 57 shows, the effect was significantly stronger in the phonetic radicals than in the semantic radicals.

8.5. Discussion and conclusions

In the first experiment, the fact that the semantic radicals, phonetic radicals and non-crucial radicals had been inverted was easily recognised when the whole characters were turned upside down as well as when in a normal Stimulus-type. The four Stimulus-types had shown dramatically different scores on the Grotesqueness Scale, indicating that the errors were effortlessly perceived regardless of Stimulus-type. Specifically, except for little variations between the performance of phonetic radicals and the other two radicals in the Normal Inverted and Grotesque Inverted conditions, the experiment revealed no support for the componential processing of character recognition. Only the phonetic radicals had a tendency to be analogous to the Thatcher Illusion in face recognition: the differences between all the characters were significant, except that between Grotesque-Inverted and Normal-Inverted (p= .130 for phonetic radicals). The first experiment on grotesque characters showed the potential difference between phonetic radicals and other kinds of radicals. In the second experiment, we compared the Normal Inverted and Grotesque Inverted stimuli, but with an additional variable: Size of changes. The results showed only the main effect of Stimulus-type. None of the other effects such as Radical and Size was significant. The third experiment showed that the Thatcher Illusion analogue happened in radicals that were approximately symmetric on both vertical and horizontal axes, and that it was more likely to happen in phonetic radicals. In this experiment, phonetic and semantic radicals showed a significant difference in the Grotesque-Inverted condition.

This off-line, "low-tech" experimental paradigm succeeded in demonstrating that configural processing is involved in encoding the relationship between the separate elements of complex Chinese characters. This configural processing contrasts with the goal of demonstrating decomposition, found in many experiments on the processing of Chinese characters. This loss of configural processing apparently only happened in characters with transformed radicals which were approximately symmetric along both vertical and horizontal axes. They were analogous to the features of the face in the Thatcher Illusion, which are themselves approximately symmetric along the horizontal and vertical axes.

In the Thatcher Illusion, broad configural processing survives inversion: the eyes, nose, mouth and hair are still seen in approximately the expected spatial relationships. However, fine configural processing is apparently lost: the distance between the corners of the mouth and the corners of the eyes seems to be lost, and the viewer appears to process the features of the face separately. In the third experiment, fine configural processing is possible when the largest part of the character is normally presented (the Grotesque condition): the participants – all native readers of Chinese – judged that the inverted radical made the whole character look grotesque. However, this fine configural processing was apparently lost when this stimulus was inverted: the precise distance between the different parts of the different elements seems to be unavailable, and the viewer appears to have the option of processing the features of the character separately. This separate processing is more likely to happen when it is the phonetic radical that has been inverted, than when it is the semantic radical. Broader configural processing survived, as the participants were able to identify all the characters. (Note that transposing the semantic and phonetic radicals in two-radical characters and then inverting the results makes the character unrecognisable to native readers of Chinese.) Again, a simple technique has demonstrated a qualitative difference between the two types of radical. This difference seems to correspond to the fact in the stimuli used, the semantic radical is the matrix part of the character, and the phonetic radical is focally important and is typically a character in its own right.

It might be argued that the transformation involving the symmetric radicals was too small to be recognized. If this were true, the Grotesque stimulus-type should have been seen as being as normal as the Normal stimulus-type. In contrast, the scores of Grotesque characters were so high that they significantly differed from other Stimulus-types. It indicated that the analogy in Chinese characters to the Thatcher Illusion was not due to the transformation being too small to notice, but to the lost fine configural processing when the characters were upside down.

The other qualitative difference between faces and characters is as follows. Recognising an upright face requires a holistic, configural coding of relative distance from the tip of mouth to the tips of eyes, nose and the other parts. This fine-grain coding is lost in an inverted face, and there remains only the broad configural coding of the features in the face, thus viewers are not able to perceive the grotesqueness of a feature with a transformed orientation. When reading upright Chinese characters, the relative distances of different parts are encoded; effectively readers have fine-grain information about the radicals themselves and broad information about the relative distances between the parts.

This study has pointed out the critical status of global processing in the recognition of Chinese character recognition. It stresses that character recognition not only involves componential processing as reported in the literature, but also involves a broader configural processing. Analogue to characters, the processing of faces also involve both broad and fine processing. According to Maurer, Le Grand, and Mondloch (2002). the differencation of broad and fine processing are further elaborated to three types: (a) sensitivity to the first-order relation (i.e. seeing a stimulus as a face by the arrangement of two eyes above a nose, and then above a mouth). (b) Holistic gestalt processing (i.e. gluing features together as a face, so that two half-overlapped faces can be separated as two whole faces). (c) Sensitivity to the second-order relation (i.e. perceiving the relational spaces between features, so that when the spaces are altered without any changes to the local features, the faces are looking different.) We suggest that further studies can be done to follow the definition of the three processing. For example, the timing of processing is still unclear, and the three types of processing might work in parallel,

The radical difference might result from the fact that the phonetic radicals are mostly an individual, pronounceable character themselves. Secondly, according to character structure phonetic radicals tend to be located in the right half of characters; position with respect to the rest of the character is more predictable in phonetic radicals than in semantic radicals. In contrast, the semantic radicals can be nested and integrated inside characters, and secondly, most of them do not have a frequently-used pronunciation. Hence they might encourage the processor to treat them more as ground than figure, compared with the phonetic radicals.

According to the results of the three experiments, we conclude that the recognition of an upright character and of an inverted character elicit different strategies, analogous to Thompson's face study. In addition, we showed that different types of radicals may give rise to different modes of processing, which might result from the physical integration of semantic radicals and the task-related features (such as in the naming task) which encourage a decomposition of phonetic radicals from the rest of the characters.

Chapter 9. General discussion and conclusions

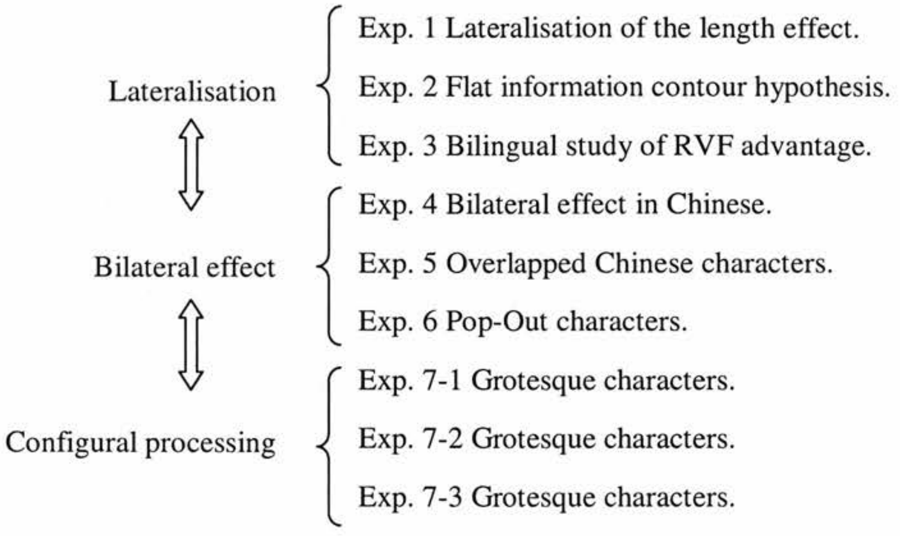

Figure 58. The three themes in this thesis.

Figure 58 lists the three themes in this thesis. In the first theme, we inspected the hemispheric lateralisation of the processing of Chinese words of different length, examined the asymmetric information contour of representative numbers of two-character and four-character words, and investigated how the information structure of a second language would assert itself in the bilingual brain with a radically different native language background. Secondly, we conducted an experiment on the Bilateral effect in Chinese to test how the density and complexity of the characters/words would affect the Bilateral advantage and further extended this study to the recognition of two stimuli of different spatial scales and of multiple numbers of stimuli. Finally, we investigated the configural processing of single Chinese characters with a series of three experiments.

9.1. Theme 1: Elimination of the LH advantage in Chinese

The two hemispheres are not lateralized in Chinese character recognition in the same way as in English word recognition. Chapter 2 showed that the robust LH advantage for longer words found in English does not occur in Chinese (Experiment 1). Studies of Chinese character recognition have shown inconsistent lateralisation effects, in a range of results from apparent absence of lateralisation through to an RH advantage (see Table 1). Even if Chinese does not always show an RH advantage, it has been argued that the characteristics of Chinese orthography have been sufficient at least to eliminate some of the LH advantage. To further discuss the English-Chinese differences in terms of hemispheric lateralisation and the word-length effect, we need to review the causes of the length effect originally discovered in English. One of the factors that arguably results in the length effect involves the splitting of the visual input, as described in the Split-fovea theory: Given that the amount of information in the two halves of a word is typically not equivalent, the brain/reader has the option of projecting more or less information to each hemisphere, by virtue of where in the word the fixation falls. The optimal viewing position observed in the reading of isolated English words lies slightly to the left of the centre, possibly because this point ensures the most even division of information between the two hemispheres. Hence, the RH is used to dealing with shorter parts of words (from the LVF), and the LH is used to dealing with the longer parts of words (from the RVF) and thus learns to deal with lengthier parts of words. This experience of the LH is then claimed to generalise to longer words.

In contrast to the Flat Contour hypothesis (and similar to English) Chinese words have a denser information profile in their first halves compared with their second halves. Chapter 3 showed that Chinese four-character words have significantly more variety in the first half than the second half when divided through the centre (Experiment 2). This asymmetry is in the same direction as the non-significant asymmetry in the more numerous two-character words. Why then did Chinese not replicate the RVF superiority found for longer English words, on the argument given above?

We saw in the Introduction that Chinese is distinct from English in (at least) three main points: dense semantic and phonetic information contained within single characters, equivalent intra-word and inter-word spaces at the word level, and variable orientations in sentences. Coincidentally all of these features concern the issue of the spatial distribution of information in Chinese characters. First, the LH length advantage may have been absent due to the fact that the RH is superior in processing spatial information. This RH advantage may have offset the LH's advantage for processing longer Chinese words. We reject this potential explanation because post hoc examination of the results showed that the male participants tended to show a LH/RVF length advantage: males typically have greater lateralization of contrasting functions such as phonology and spatial processing, so their RH spatial processing should have been able to compensate for any LH tendency to deal effectively with longer words.

A second potential explanation is that Chinese readers are exposed to vertical text for a large proportion of their reading and the LH simply does not have sufficient experience of left-to-right words being fixated to the left of centre to learn to deal with such words effectively, and to learn to deal with longer parts of words better than the RH. This interpretation is supported by Chapter 4 the bilingual study, where Chinese(L1)-English(L2) bilinguals showed a tendency towards a RVF advantage in the recognition of English words, but there was no significant visual field by word interaction (Experiment 3). The RVF advantage of function word recognition observed in English monolinguals might have been constrained by the established configuration of bilinguals' native language background, specifically with respect to syntax.

A third contribution to the absence of the length by hemispheres interaction in Chinese concerns the complexity of Chinese orthography. As concluded in Chapter 2, the complexity of characters and words in Chinese may also play a role in the elimination of any RVF advantage. (These factors were tested in Chapters 5 and 8, respectively.) Even though readers are exposed to words with asymmetric informational content, and even though they show a degree of parafoveal processing, the complexity of Chinese orthography still demands predominantly character by character processing for words greater than two characters in length. This type of processing is fundamentally different from the reading of longer words in English. It does not permit the length by hemisphere interaction to appear.

Finally, related to the elimination of a RVF advantage for the Chinese readers, we make a further suggestion. The majority of single characters comprise both phonetic and semantic radicals; further, the processing of Chinese characters is reported to be mediated by a decompositional process in which the phonological radical is processed separately (Zhou, 1999a, 1999b). This state of affairs may be advantageous to Chinese readers in the elimination of RVF advantage: the phonological radical typically appearing on the right of the character will tend to be initially projected to the LH, to which expressive phonology tends to be lateralised in the brain. This may be an explanation of the elimination of any processing advantage observed in several of the experiments reported here.

9.2. Theme 2: Bilateral effect in Chinese character recognition

The second theme examined the complexity issue discussed in the first theme. Given that English and Chinese have qualitative processing differences, the Bilateral advantage becomes intriguing in the case of complex Chinese characters. Chapter 5 showed that there was overall no significant Bilateral effect using the classic bilateral presentation paradigm (Experiment 4). In line with other (non-Chinese and non-linguistic) studies reported in the literature, the data showed a (non-significant) tendency for the Bilateral effect to occur in Chinese only when the word lengths were more than three characters long; that is, the longer a word is, the more the bilateral presentation – compared with the unilateral presentation – tended to contribute to word recognition. This suggests that when the complexity of a task increases to a critical level, the two hemispheres will start collaborating to complete the task. Otherwise, they will typically process a task unilaterally using the specialized hemisphere that is more efficient for that particular task.

In contrast to the absence of a classic Bilateral effect, a significant redundancy effect was successfully demonstrated using a version of the Pop-out procedure (Experiment 6), in which I showed that multiple unattended versions of the target character in the background, but in parafoveal vision, significantly facilitated recognition of the target. This procedure was more transparent in terms of preattentional processing of the non-target stimulus materials than was the classic Bilateral paradigm. I suggest that the two background versions of the target in closest proximity (left and right) to the target were the most influential in facilitating the recognition of the target. Such a "triple" of characters ensures, by virtue of the split-fovea model, that each hemisphere receives the full complement of information about the target's component radicals.

Experiment 5 demonstrated that there are severe constraints on the types of redundancy that can facilitate character recognition. A character that was repeated, centred on the same fixation point but at a different spatial scale, was not recognised faster than a single version of the character.

There are three factors potentially affecting the occurrence of the Bilateral effect in Chinese. The first factor was the spatial complexity of Chinese words. As shown in Chapter 5, five-character words are far more complex than three-character words and two-character words, if counted in terms of the orthographic, phonetic, semantic and morphological information possibly contained both in the characters and in the possible words. This explains why there was a (non-significant) tendency towards a graded bilateral advantage from five-character, through three-character to two-character words, in line with the literature on the effects of complexity on the bilateral advantage.

The second factor was demonstrated by a model based on foveal splitting and incorporating parafoveal vision. We have explained above how information about the non-fixated word(s) in parafoveal vision might be of assistance to the target character. This argument also holds for vertically presented multi-character words. Whether or not a bilateral advantage occurs for such words may be decided by other factors.

The third factor was what we have called Gestalt perception. Gestalt effects have been long recognized within Psychology. They were first identified at a time when there did not exist the computational insights to model such effects. Currently, models of visual processing are able to capture Gestalt-like visual effects such as completion or certain apparent-occlusion phenomena by modelling the ways in which networks of neurons capture regularity in the visual world. Our use of the notion of Gestalt perceptual phenomena is more descriptive than explanatory; such effects are real at the perceptual level and seem to trade on degree of complexity of the visual stimulus and also seem to be related to the general issue of redundancy in processing. Such terminology is never invoked in the study of the processing of alphabetic languages, but it is arguably more relevant in the processing of Chinese orthography.

In conclusion, we have shown that informational and spatial complexity determine some of the limits of the bilateral advantage in the processing of Chinese orthography. The advantage does not reliably occur in the classic bilateral paradigm but can be made to occur in certain situations of redundancy (as in multiple unattended background versions of the target) and not in others (as in redundancy at different levels of spatial scale).

9.3. Theme 3: Processing of single Chinese characters

Given that spatial complexity is essential in Chinese single characters as well as in words and apparently may contribute to the occurrence of the Bilateral effect, we inspected single characters and the related processing in the third theme. Chapter 8 showed that the symmetry (or lack of it) of the radicals was a crucial factor in the Thatcher Illusion and character recognition, although the illusion did not initially seem applicable to the recognition of Chinese characters (Experiments 7-1, 7-2). When the inversion of radicals was constrained to be approximately symmetric about a horizontal axis and a vertical axis, Chinese readers experienced an analogue of the Thatcher Illusion for characters comprising those radicals (Experiment 7-3). In addition, different types of radical might play different roles or have different modes of processing. The recognition of Chinese characters involves broad and fine configural processing for the identification of a character and for the access to phonology and semantics through the orthography. Phonetic radicals apparently require more focal processing and semantic radicals acquire more global processing, possibly due to the fact that the semantic radical is the matrix part of the character, and the phonetic radical is focally important and is typically a character on its own. When semantic radicals are processed, more weight is given to global and long-range information about the relationship of the semantic radical to other parts of the character. This information tends to survive inversion. In contrast, the configural information required by the phonetic radical does not tend to survive inversion. As 60% of Chinese characters are composed of a phonetic radical and a semantic radical, the complexity issue concerning these two radicals is definitely an essential factor in Chinese character recognition.

In conclusion, the recognition of Chinese single characters overall involves configural spatial processing. The issue of spatial complexity is implicated in Chinese character recognition from the most basic to the most complex units: stroke patterns, radicals, characters, single and multiple character words, and sentences. Hence, the reading of Chinese is more likely to involve the fine-grain spatial processing, tending to reduce the pattern of LH lateralisation found in alphabetic languages.

9.4. Further studies

9.4.1. Experiment of male participant for lateralisation

It is important to note that there are relatively small numbers of participants used in these experiments due to difficulty recruiting native Chinese speakers, especially those skilled in traditional Chinese. A larger sample of participants would have shown a clearer result and higher reliability. In the first theme the word-length effect and lateralisation has shown the potential difference in the two genders in terms of hemispheric lateralisation in the processing of Chinese character recognition. It has been known that male and female have anatomic differences in the brain. For instance, Ghose and Maunsell (2002) show that the female corpus callosum tends to have a larger splenium than the male corpus callosum; Shaywitz and colleagues (1995) showed that there tends to be less extreme lateralization in the female brain. In our experiment male participants also tended to show lateralisation more than the female participants. To further study hemispheric lateralisation and to avoid the ceiling effect made by quickly transferring between the two hemispheres of females, it is worth examining lateralisation based on male participants. The proposed experiment would enlarge the number of participants matched male and female to explore the gender difference in a further study.

9.4.2. Blurred outsides of words: Initial fixation in the bilateral presentation

As shown in the second theme concerning the Bilateral effect, we proposed a model to show how participants' initial fixation of the bilateral presentation could give rise to the Bilateral advantage over a unilateral presentation: the bilateral presentation projected to the two hemispheres made a word image complete, whereas in the unilateral presentation the LH had only half of the image even when the presentation was in the middle of the field, overlying the initial fixation point. This demonstration was based on the fact that images in parafoveal vision are more blurred than those projected to the fovea. It would strengthen the model if word recognition of a bilateral presentation remained the same with and without the blurring of the outer half of the words. The proposal for further study is to split Chinese words into left and right halves, and present them as was done in Chapter 5. The lack of change in recognition latency will test the assumption of visual perception and eye-movement required in the bilateral presentation.

9.4.3. The loss of fine configural processing of Chinese characters

As earlier mentioned in the third theme, involving grotesque characters, viewers could recognise Chinese characters because there was a broad configural processing of Chinese characters, encoding the features and the relative distances between the local features of a character. This processing survived in the inverted version of characters, and gave viewers no difficulties in naming inverted characters. However, as Experiment 7-3 showed, an inverted character lost some of its fine configural processing and so viewers were unaware of the grotesqueness of the transformation of the radicals, especially the symmetric radicals. Furthermore, the tendency shown by the series of experiments also indicated the qualitative difference between phonetic and semantic radicals in Chinese characters. They might have been involved in different modes of processing when embedded in Chinese scripts. The original study was done with three off-line experiments, and I believe the loss of fine configural processing would be more apparent if examined on-line. This on-line paradigm could ensure a speedy presentation and brief exposure of characters to the viewer, and ensure that viewers were less able to rotate the word stimuli mentally.

9.4.4. Computational modelling of single Chinese characters

Computational modelling is worth examining to explore the reader's acquisition of phonological and semantic information about Chinese characters. Given that radicals in single Chinese characters provide information about phonology and semantics for the character, it might be possible to find underlying informational strategies concerning how people recognise a character and name it. Different combinations of radicals lead readers to diverse pronunciations of characters. For example, "靜" is named "jing4" (meaning "quiet") and "清" is named "ching1" (meaning "clear"), depending on what is attached to the phonetic radical "青" (pronounced as "ching1", meaning "green"). The pronunciations of the two characters are different but there is a general principle that means that these two are pronounced similarly to "ching1", or at least, have the identical vowel "ing". Another example, characters "鮪" (named "wei3", meaning "salmon") and "鯉" (named "Li4", meaning "carp or studfish") both have the semantic radical "魚" (named "yu2", meaning "fish").

The training of a neural network cognitive model may be a plausible project for connecting character recognition with the radicals of pronunciation and semantics.

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Appendix 1.

Stimuli of Experiment 1 Length effect and Experiment 4 Bilateral effect[4].

2-character realwords	2-character nonwords
歹徒 bandit	史歷 history
朋友 friend	晶結 crystalloid
文化 culture	機司 driver
辭呈 resignation letter	治政 politics
枕頭 pillow	音聲 sound
孤兒 orphan	示指 instruction
塑膠 plastics	然自 nature
語氣 tone of speech	容內 content
饅頭 steam dumpling	律旋 melody
抱負 ambition	宙宇 universe
學生 student	笑微 smile
糾紛 disputation	戚親 relatives
耳朵 ear	睛眼 eye
馬路 road	候氣 climate
時間 time	度制 system
年紀 age	鵑杜 azalea
才華 talent	驗經 experience
風格 style	案答 answer
生活 life	應反 response
原則 principle	氛氣 atmosphere
乞丐 beggar	隸奴 slave
麵包 bread	戰挑 challenge
香片 fragrant leaf	師老 teacher
玫瑰 rose	仰信 relief
風度 style of personality	突衝 conflict

[4] Chinese words are listed with their English translations. Non-words are translated with the original meanings before transformantion.

3-character realwords	3-character nonwords
臭皮匠 a cobbler	老姓百 the common people
螺絲釘 screw	話子匣 chatter box
贍養費 alimony	收率視 the rate of TV program being watched
超音波 ultra sound	董長事 a board director
不鏽鋼 stainless steel	自心信 confidence
萬花筒 kaleidoscope	顯鏡微 microscope
千斤頂 jack	霓燈虹 neon light
大夜班 night shift	排榜行 charts of the pops
搖滾樂 rock'n roll	原民住 native resident
作業員 operator	過兒動 excessively active children
掛號信 registered letter	獨俠行 a man who acts alone
獎學金 scholarship	劣性根 degraded character
專利品 patent	老婆太 old woman
零用錢 allowance	苦計肉 a faked trick for sympathy
近視眼 nearsightedness	里碑程 milestone
可塑性 plasticity	基徒督 Christian
留學生 overseas student	黑會社 underworld society
原子彈 atomic bomb	錄帶音 tape
計程車 taxi	垃堆圾 trash stack
小品文 essays	暴戶發 nouveau riche
荷包蛋 fried egg	陽麵春 plain soup-noodles
無名指 ring finger	護符身 an amulet
臭豆腐 fermented tofu	主曲題 song of the theme
轉捩點 watershed	安感全 secure
傳染病 infectious disease	平心常 calmness

5-character realwords

十八般武藝 eighteen skills
綜合所得稅 consolidated income tax
後印象畫派 Postimpressionism
凍頂烏龍茶 a kind of tea raised in Mountaintop
通貨膨脹率 inflation rate
聖誕老公公 Santa Claus
碳水化合物 carbohydrate
生日快樂歌 Birthday song
吃角子老虎 slot machine
廬山真面目 true character
半自助旅行 backpacker
戰士授田證 certificate of estate for warriors
中華民國頌 Song for Republic of China
四角號碼類 a coding method of Chinese
五權憲法制 constitution
公共電話卡 telephone card
大腸桿菌群 Escherichia coliform
商品標示法 regulations for labelling merchandise
沙文主義者 chauvinist
大眾心理學 public psychology
熱門音樂會 concert of pop music
省教育廳長 head of dep. of education of province
高爾夫球場 golf course

5-character nonwords

公共車汽站 bus station
調虎山離計 a trick to attract a tiger out of its mountains
野生物動法 wild-animal regulation
心肺甦復器 CPR
文學革論命 a literary revolution
文復藝興期 renaissance
打擊樂器組 group of percussion instrument
守望相隊助 neighbours in a community to help each other in guarding against enemies
君主憲立制 constitution monarchy
沈默寡型言 taciturn style
後現主代義 post-modernism
產道業路線 industrial way
天怨尤人型 negative thinking style
食品生衛法 regulations of food nutrition
核磁振共儀 fMRI
特教殊育科 department of special education
向逆思考法 thinking in an opposite direction
精神裂分症 Schizophrenia
謀財命害案 murder
諮商導輔室 consulting and counselling room
都市畫計法 an urban renewal plan
國際易貿系 department of international trade
亞太融金區 Asian and the Pacific financial area

Appendix 2.

Stimuli of Experiment 3: Bilingual study

Function words	
One syllable, high frequency	yet, why, thus, shall, whose, am, nor, whom, none, ought.
Two syllables, high frequency	rather, often, ever, whether, either, further, except, neither, herself, unless.
One syllable, very high frequency	then, now, such, our, me, must, your, much, where, just, those, how, here, though, while, might, us, since, once, less.
Content words	
One syllable, high frequency	foot, arm, fire, road, way, hard, red, view, low, wish.
Two syllables, high frequency	remain, office, mother, money, letter, father, music, occur, agree, machine.
One syllable, very high frequency	say, man, see, walk, find, look, world, hand, long, house, child, ask, eye, head, face, run, high, war, room, light.
Non-words	loyt, stuld, thyll, fasp, wem, roog, noom, rhas, nelt, oune, erthar, netor, veret, herew, reitoon, ruhert, expty, heinert, sherfel, seluns, mook, fraf, vad, yod, roak, harw, rel, sar, wod, shiw, reinam, iffpce, rethom, rassar, rertel, tharef, cimus, rucco, rega, nachime, hent, wogh, heb, surm, rez, sumt, moop, rach, arn, jors, hosk, splog, heerf, mool, howt, thom, stum, neesh, sonc, leb, yeam, namp, ress, wak, noif, echs, quab, lurv, haar, shaf, ilch, swaz, yees, veas, heaf, swad, naz, reen, nase, grif.

Appendix 3.

Stimuli of Experiment 5: Overlap characters

Low frequency (Frequency <10)		High frequency (Frequency= 3510~10000)	
Real characters	Non characters	Real characters	Non characters
媳	鉀	天	國
邵	厘	曾	李
鈾	餉	組	點
硯	恙	市	股
鈣	篙	王	區
蚋	亢	處	起
蚌	尉	事	號
滇	箏	車	文
渾	筐	間	成
鮪	鹵	鎮	金
蓆	腮	本	場
籽	柒	部	些
芯	荀	省	隊
陜	庾	作	女
碘	瓢	華	某
嬸	鎢	性	法

Practice trials	
Low Freq	**High Freq**
茭桅	線南
蛆熞	方姓
柚畦	美水
賬臼	局廠
杓蛾	商遭
錳虫	盤海
荻閭	幾行
鮫盹	半期
胰綏	東道
箋紂	安開
莒蛹	福
喙俺	
痂鋰	
杵郃	
瘍薛	
疤	

Frequencies are the number of words found in a corpus of 29540444 words (Chinese knowledge information processing group, 1993).

Appendix 4.

Stimuli of Experiment 6: Pop-Out effect

	High frequency character		Low frequency character	
	Target characters	Background character	Target characters	Background character
Real characters	天曾	省部	媳邵	芯蛾
	組市	道作	鈾硯	嬸蛊
	王處	裔本	鈣蚋	腴箋
	事車	華海	蚌溳	痂鋰
	性線	道部	蓆籽	蛾嬸
	南方	省作	錳陜	芯蛊
	姓遭	華裔	碘綏	腴箋
	盤東	海本	紂杵	痂鋰
Non characters	國李	場福	鉀厘	莒蘚
	點股	期半	餉恙	瘍俺
	區起	行幾	篙亢	喙蛹
	號文	廠局	尉箏	疤鮫
	開些	場福	腮柒	莒蘚
	隊女	期半	荀庾	瘍俺
	某法	行幾	瓢荻	喙蛹
	美水	廠局	閭盹	疤鮫

Appendix 5.

Instruction of Experiment 7-1: Grotesque characters

In this Experiment you will see some normal and some odd Chinese characters. What you need to do is to draw a circle on a five-scale measurement to indicate how odd you feel it is. Number 5 represents the most odd and number 1 means feeling-OK. Make the judgment by the first impression as soon as you can.

☺ **1..........2..........3..........4..........5** ☹

Example of answering sheet of Experiment 7-1: Grotesque characters

溪

☺ 1……….2……….3……….4……….5 ☹

Materials of Experiment 7-1: Grotesque characters

Semantic radicals	Phonetic radicals	Non-crucial radicals
繳	寢	疑
橢	薄	募
檻	擷	殺
緞	鄰	戀
讀	照	樂
場		騎
壩		徽
燃		蘊
鍥		瀕
襁		繫
蟒		蔓
穆		溜
孽		溪
築		囉

Example of answering sheet of Experiment 7-2: Grotesque characters

Name-__________________________Gender-_____________Date-_______________

ISS1	☺ 1…………….2…………….3…………….4…………….5 ☹
INB1	☺ 1…………….2…………….3…………….4…………….5 ☹
PS1	☺ 1…………….2…………….3…………….4…………….5 ☹
SB1	☺ 1…………….2…………….3…………….4…………….5 ☹
INS1	☺ 1…………….2…………….3…………….4…………….5 ☹
IPB1	☺ 1…………….2…………….3…………….4…………….5 ☹
SS2	☺ 1…………….2…………….3…………….4…………….5 ☹
NB2	☺ 1…………….2…………….3…………….4…………….5 ☹
IPS2	☺ 1…………….2…………….3…………….4…………….5 ☹

Materials of Experiment 7-2: Grotesque characters

Size of transformation	**Phonetic radical**	**Semantic radical**	**Non-crucial radical**
Large	桑	脅	壘
	響	參	戀
	潔	礎	膠
	擊	醫	續
	歷	魔	顯
Small	鬆	歸	殺
	擷	瀕	徽
	築	孽	藍
	寢	籍	護
	照	盤	蘊

Materials of Experiment 7-3: Grotesque characters

Characters	Radicals transformed	Symmetry	Radical type
壘	田	H & V	Phonetic
續	四	H & V	Phonetic
護	口	H & V	Semantic
潔	丰	H & V	Phonetic
藉	日	H & V	Phonetic
顯	曰	H & V	Phonetic
照	口	H & V	Phonetic
殺	儿	V	Semantic
響	音	V	Semantic
孽	子	Asymmetry	Semantic
築	竹	Asymmetry	Semantic
藍	皿	V	Phonetic

H&V: Approximately symmetric about horizontal and vertical axes.

V: Approximately symmetric about a vertical axis.