The Role of Radical Information in Chinese Character Recognition

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Abstract of thesis entitled:

The role of radical information in Chinese character recognition

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This research was designed to examine the processing of different kinds of radical frequency information, i.e. frequency as a position-free radical, frequency as a position-specific radical, and frequency as a stand alone character. Whether the task or the composition of materials could influence the processing of such information was also examined. The first two were behavioral experiments and results indicated that effect of the position-free radical frequency was stable across the lexical decision task (Experiment 1) and the position decision task (Experiment 2). Effect of the position-specific radical frequency emerged only when the lexical decision task was available (Experiment 1).

In Experiments 3 and 4, event-related potentials were recorded to verify the findings of the first two behavioral experiments. Similarly, Experiment 3 employed the lexical decision task and Experiment 4 used the position decision task. First, results revealed that a series of ERP components (P150, P200, and N400) were found to be related to the effect of position- specific radical frequency when the lexical decision task was used (Experiment 3). However, when replacing the lexical decision task with the position decision task but keeping illegal characters as fillers, the effect of position-specific radical frequency became quite weak, which was only associated with P200 (Experiment 4a). Moreover, when using the position decision task but replacing illegal characters with geometric figures as fillers, there were no effects of

position-specific radical frequency any more (Experiment 4b). Second, the task was found to influence the time course for effects of position-free radical frequency, which was reflected by P200 in the lexical decision task (Experiment 3) and by N400 in the position decision task (Experiments 4a and 4b). Finally, simple character frequency could play a role in processing compound characters in which simple characters were used as radicals, but such effect was significant only in the position decision task and it was reflected by a change in N400 (Experiments 4a and 4b).

These findings indicate that position-specific radicals could play a role in character recognition, but this effect appears to be constrained by the task and/or the composition of materials. In contrast, effects of position-free radicals keep stable across different tasks and composition of materials. In addition, the findings also suggest that simple character information could exert influence on compound character processing, but only when characters are processed implicitly (e.g., in the position decision task). Implications of this research and future directions are discussed.

摘要

本研究旨在探讨各种不同类别的部件频率信息：不携带位置信息的部件频率(frequency as a position-free radical)，携带位置信息的部件频率 (frequency as a position-specific radical)以及部件作为单字的频率(frequency as a stand alone character) 在汉字加工中的作用以及作用的时程。同时，本研究也探讨了任务范式和材料对不同类别的部件频率信息加工的作用。实验 1 和实验 2 的结果显示，无论采用真假字判断作业（实验 1）还是采用位置判断作业（实验 2），不携带位置信息的部件频率在汉字识别中产生了重要作用；而携带位置信息的部件频率只在真假字判断（实验 1）作业中才能发挥作用。

实验 3 和实验 4 采用脑电技术进一步探讨此问题。同理，实验 3 采用真假字判断作业，实验 4 采用位置判断作业。结果表明：首先，在真假字判断作业中，携带位置信息的部件频率引发了 P150，P200，N400 一系列脑电成份的变化（实验 3）；而当采用位置判断作业，但保留假字的存在时，携带位置信息的部件频率对汉字加工的作用强度明显变小，只表现在 P200 的变化上（实验 4a）；此外，当只保留位置判断作业而不采用假字为填充材料时，携带位置信息的部件频率不再对汉字加工产生作用（实验 4b）。其次，不同的作业会导致不携带位置信息的部件频率对汉字加工的作用在时程上产生变化，真假字判断任务似乎会使该作用提前，引发了 P200 的变化（实验 3）；而在位置判断(position decision)作业中，不携带位置信息的部件频率引发了 N400 的变化（实验 4a 和 4b）。最后，该结果还表明，部件作为单字的频率信息可以对汉字加工产生作用，但只表现在位置判断作业中，会引发 N400 的变化（实验 4a 和 4b）。

该研究结果表明携带位置信息的部件可以对汉字加工产生作用，但是该作用似乎受到任务和材料的限制；而不携带位置信息的部件对汉字加工的作用不受任务和材料的限制。此外，部件作为单字的信息可以对汉字加工产生作用，但是要在一定的条件下才能发生。基于本系列研究的结果，本论文探讨了其意义以及继续研究的方向。

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Chapter 1

Introduction

Chinese characters are the basic writing units in the Chinese script and character recognition is therefore fundamental to Chinese reading (Chen, 1992, 1999; Hoosain, 1991). Given the importance of Chinese characters, a number of studies have focused on how characters are recognized, such as how orthographic, phonological, and semantic information of a character are retrieved (e.g., Hsiao, Shillcock, & Lavidor, 2006; Liu, Tian, Li, Gong, & Lee, 2009; Meng, Jian, Shu, Tian, & Zhou, 2008; Taft, 2006; Tsang & Chen, 2009; Tzeng, Hung, Cotton, & Wang, 1979; You, Chen, & Dunlap, 2009). In the present study, we focus on the role of orthographic information in Chinese character recognition. In the introduction section of this dissertation, we first give a brief description of the Chinese orthographic system, and then provide a summary of current research on orthographic processes in Chinese character recognition, describing some of the central areas of empirical investigation, and the major theories guiding that work.

1.1 Chinese orthographic system

Orthography of a language specifies the way it is written. In other words, orthography describes or defines the set of symbols used and the rules for writing the symbols. In alphabetic languages, the orthographic system can be described at two different levels, that is, letter level and word level. Words either contain at least one letter that is different from other words (e.g., who and why), or the same letters but in a different sequence (e.g., who and how). In the Chinese orthographic system, there are more orthographic levels, i.e. Strokes, radicals, characters, and words. A Chinese word contains one or more characters, which in turn are composed of one or more radicals. A radical is composed of a signal stroke or a cluster of strokes. Besides, many characters can appear in different positions within a compound word. For example, character 务 (wu4, affair) can occur on the left (e.g., 务必, must), on the right (e.g., 义务, obligation), or in the middle (e.g., 服务部, service department). Similarly, many radicals can appear at different positions within a character. For instance, radical 口 can occur on the left (e.g., 听 ting1, listen), on the right (e.g., 知 zhi1, know), at the top (e.g., 呆 dai1, stupid), at the bottom (e.g., 杏 xing4, apricot) or in a range of several other positions in more complex characters (e.g., 语 yu3, speech; 停 ting2, stop; 熟 shu2, ripe).

Particularly, there are two sub-lexical orthographic levels in the Chinese orthographic system, that is, radicals and strokes. Strokes are the smallest structural units in the Chinese writing system. There are five kinds of strokes: horizontal line, vertical line, dot, oblique line, and curved line (A Dictionary of Chinese Character Information, 1988; Fu, 1985). In linguistics, radicals can usually refer to components that serve as indexes when people look up a dictionary (Wang, 1981). The Chinese name for such a component is bushou (部首). However, Bushou is a limited concept which does not include all components of a character. One character contains only one bushou, the rest are decomposed into strokes. For instance, the character "铜 tong2, copper" is composed of a bushou "钅" and six strokes (decomposition of 同). Later, researchers (Chen, Zhou, & Chen, 1987) in linguistics introduced another concept- all components of a character, regardless of their function, tend to be given the unified name of a radical (i.e. bujian, 部件 in Chinese). However, in this dissertation, the term radical refers to all constituent components of Chinese characters. There are around 648 radicals that constitute around the 7,000 Chinese characters (A Dictionary of Chinese Character Information, 1988; Fu, 1985).

In alphabetic languages, letters (components of words) themselves generally have no meanings. But in Chinese, radicals of characters often have their own meanings. In Chinese characters, over 90% are structurally compound characters (A Dictionary of Chinese Character Information, 1988) and around 80% are phonetic compound characters (Honorof & Feldman, 2006). Compound characters are defined as characters containing two or more radicals. A phonetic compound character is usually composed of a semantic radical carrying some semantic information, and a phonetic radical carrying some phonological information. For example, the “钅“ of “铜” often refers to metal-related characters, whereas, pronunciation of “同 tong2” provides a phonological indication for that of “铜 tong2”.

Besides, in the Chinese orthographic system, it is quite common for a certain component to have multiple identities. In Chinese, around 82% of words are single character words (Modern Chinese Frequency Dictionary, 1990). Moreover, in characters, around 50% radicals (such as “同” in “铜”) can be used as independent characters also (A Dictionary of Chinese Character Information, 1988). Actually, even a stroke itself (e.g., “一”) can be used as an independent character or even a word. This is quite different from most alphabetic languages, in which, except some very few letters, such as “A” and “I” in English, could be used as words; most letters are just letters, they become words only when combined with other letters.

Given these special properties, we could conclude that findings from research on alphabetic word processing may not be readily applied to the Chinese orthographic system. In other words, notwithstanding, the fruitful results and the relatively definitive conclusions about orthographic processing in alphabetic word recognition, the same may not be assumed to be universal phenomena across different languages (Grainger, 2008, a review). Thus, to develop a comprehensive model of orthographic processing, studies on Chinese with distinct prosperities different from alphabetic orthography are evidently in need. Actually, over the past few decades, more and more studies on Chinese character recognition have been conducted, and relatively fruitful results have been obtained.

1.2 Previous findings in the field of Chinese orthographic processing

Extant research which has explored Chinese orthographic processing can be divided into three categories. The first one covered the studies to investigate the orthographic processing through manipulating the radical's functional information, namely, a radical's semantic or phonetic function (e.g., Feldman & Siok, 1997, 1999; He, Yin, Luo, & Weekes, 2006; Hsu, Tsai, Lee, & Tzeng, 2009; Lee et al., 2004; Lee et al., 2007; Su & Weekes, 2007; Zhou & Marslen-Wilson, 1999a). The second one covered the examination of the effects of orthographic information through manipulating a radical's structural information, such as a radical's form or its position (e.g., Ding, Peng, & Taft, 2004; Ding, Taft, & Zhu, 2000; Lai & Huang, 1988; Li, 1998; Li & Chen, 1999a; Li & Chen, 1999b; Taft, 2006; Taft & Zhu, 1997; Taft, Zhu, & Ding, 2000; Taft, Zhu, & Peng, 1999; Tsang & Chen, 2009; Yeh & Li, 2002). In the first two categories, researchers explored the nature and the time course of orthographic effects through manipulating the information of a radical as a radical. However, in the third type of studies, the roles of orthographic processes were investigated through manipulating the information of a radical as a character, i.e. the information of a radical's simple character version (e.g., Ding et al., 2000; Ding et al., 2004; Lee, Tsai, Huang, Hung, & Tzeng, 2006; Perfetti & Tan, 1999; Zhou & Marslen-Wilson, 1999b).

1.2.1 Orthographic effects through manipulating the radical's functional information

In recent years, many researchers have paid attention to the effects of radicals' functional information in compound character recognition. In the studies focusing on this issue, researchers usually manipulate combinability of a semantic or phonetic radical, which refers to the number of characters that share a semantic radical, or the number of characters that share a phonetic radical. Both behavioral and neurophysiological studies have confirmed the effects of radicals' combinability on visual character recognition. Besides, most neurophysiological evidence reveals that the radicals' combinability has an early effect on character processing, around 200 ms after the stimulus onset (e.g., He et al., 2006; Hsu et al., 2009; Lee et al., 2004; Lee et al., 2007). Because a radical's combinability to some extent reflects the density of orthographic neighborhood of a character that contains this radical, some researchers (e.g., Lee et al., 2004) argue that these findings demonstrate that the orthographic information could exert influence in the early stages of character processing, i.e. before the semantic processing of the character.

1.2.2 Orthographic effects through manipulating the radical's structural information

The primary concern of the structural approach is not the functional roles radicals play but how radicals are represented in the mental lexicon, i.e. position-specific or position-free. One proposal concerning this argument assumed that each radical is represented with positional codes in human mental representations. Accordingly, radicals such as "日" embedded in characters "明 ming2, bright", "早 zao3, morning", "晶 jing1, crystal", etc, have distinct representations and each of them carries its positional information in the corresponding character.

Evidences of position-specific radical representations were reported by Taft and his colleagues (e.g., Ding et al., 2004; Taft et al., 1999; Taft & Zhu, 1997). Taft and Zhu (1997) discovered that radical frequency affected the reaction time (RT) of characters in a lexical decision task (LDT). The decision time to items with radicals appearing in many characters (i.e. radical frequency is high) was faster than to those with radicals appearing in only a few. However, the frequency count was found to be position-dependent. In other words, only when an item shared a particular radical with a larger number of characters remaining in the original positions of that radical, its RT was faster. In contrast, when an item shared a particular radical with a larger number of characters in which the radical appeared regardless of positions, no facilitation effect was found, relative to its control condition. A similar evidence of position-specific radical effects was also found in Ding, Peng, and Taft (2004), in which a primed character decision task was used. Results revealed facilitative priming when the prime and the target shared the radical at the same position (e.g., "躯 qu1, body" can prime "枢 shu1, pivot"), but no such effects were observed when the shared radical appeared in a different position (e.g., "欧 ou1, Europe"can not prime" 枢").

Given this evidence, it seems reasonable to conclude that radical positional information plays an important role in visual character recognition. However, when considering the findings for the effects of position-free radicals (e.g., Lai & Huang, 1988; Li & Chen, 1999b; Tsang & Chen, 2009; Yeh & Li, 2002), the situation becomes complicated. One such study was conducted by Yeh and Li (2002), who used visual search paradigm. In this study, participants were requested to search a target character (e.g., 納 na4, bring into) either in an array of radical-sharing characters or in a set of structure-matched control characters. Results revealed that it was more difficult to search a target (e.g., 純 chun2, pure) among a series of characters sharing with the target character the same radical "糸" at the same position than among an array of control characters (e.g., "缺 que1, lack"). More specially, even among a set of characters sharing the same radical with the targets, but in a different position (e.g., "素 su4, plain"), the search task became more difficult than among its control characters (e.g., "旁 pang2, side"). If the claim of position-specific radical representation was right, "素" should not produce significant interference in detection of "納" because radical "糸" in "納" and "素" would have distinct representations which should not interfere with each other.

Another set of evidence against the view of position-specific radical representations comes from studies adopting an illusory conjunction paradigm (e.g., Lai & Huang, 1988; Li & Chen, 1999b; Tsang & Chen, 2009), where several characters (usually called source characters) were presented briefly, either serially using a rapid serial visual presentation technique or simultaneously. After the source characters, a probe character will be presented and participants are required to report whether they have seen it. Often, the relationship between source characters and the probe will be manipulated. Using this technique, Tsang and Chen (2009) found that participants were more likely to illusorily report "和 he2, and" after the brief presentation of source characters "秋 qiu1, autumn" and "吐 tu4, spit" even when the radical's position was mismatched (Experiment 1). Moreover, it was found that even when sharing only a single radical between the probes ("秸 jie2, straw" or "頡 jie2") and source characters ("結 jie2, knot" and "栓 shuan1, plug"), either at the same position ("秸") or at another ("頡"), it was enough to generate an illusory character. This finding is clearly inconsistent with the position-specific account of radical processing. In accordance with the position-specific view of radicals, we predict that no illusory characters with cross-positioned radicals should be perceived, because radicals in different locations are separately represented and should not be confused with each other. Given these inconsistent findings, nowadays, researchers are looking for the possible reasons. For instance, some researchers (e.g., Tsang & Chen, 2009) argued that the material composition might be an important factor to account for the different effects of radical positions. However, little research has been conducted to follow this argument.

1.2.3 Effects of a radical's simple character information on compound character recognition

When a radical itself is a legal simple character (e.g., "日 ri4, sun" and "月 yue4, moon" in "明"), the question is usually raised concerning whether the orthographic information of its character version would play a role in compound character processing, and if it could, what the relationship between it and its radical version is. As for these issues, Ding et al (2004) reported the priming effect of simple characters in processing of compound characters. It was found that pre-exposure of the simple-character prime (e.g., "乏 fa2, tired") facilitated recognition of a compound character (e.g., "砭 bian1") in which the simple character was used as a radical (Experiments 1 and 2). This priming effect was not due to the similarity in features between the prime and the target because a similar prime "之 zhi1" indeed inhibited processing of "砭" (Experiment 2). Besides, researchers also found that even the semantic information of a radical's simple character version could be activated during the compound character processing (e.g., Lee et al., 2006; Zhou & Marslen-Wilson, 1999b).

Concerning the relationship between representations of a simple character and its radical version, different models have different views. In some models, researchers (e.g., Ding et al., 2004; Taft, 2006) assume that when a radical is a simple character, its character level and radical level representations are combined together into one position-free "simple character" representation in orthographic representation of Chinese characters. However, in other models (e.g., Perfetti & Tan, 1999), researchers suggest a kind of redundancy that gives simple characters both independent and compositional representations. Next, we introduce these models in detail.

1.2.4 Relevant models

Among models illustrating the identification course of character recognition (e.g., Perfetti, Liu, & Tan, 2005; Taft, 2006; Zhou, Shu, Bi, & Shi, 1999), the Multilevel Interaction Activation Model proposed by Taft and his colleagues (see a review, Taft, 2006), elaborates orthographic processing most extensively. Given the findings that both position-free and position-specific radicals could exert influence on character recognition, this model first confirms the existence of both kinds of radical representations and then describes the relationship between them, as well as the time course of the whole character processing (see Figure 1).

There are three subsystems in this model: orthography, phonology, and semantics. In the orthographic subsystem, a hierarchical activation framework is proposed. A visually presented character first activates visual feature unites representing strokes or stroke intersections, etc. Then the activating information activates form-level units presenting the relevant radicals, which in turn sends activation information onto form-level units representing characters that contain those radicals. Two points in this model need to be noted. First, when a radical is a simple character, the representation of its simple character version is the same as its radical version. Second, radicals are explicitly represented and the representations are position-specific. A compound character is recognized via position-specific representations of its radicals and these, in turn, are activated through an abstract position-free radical associated with its positional information.

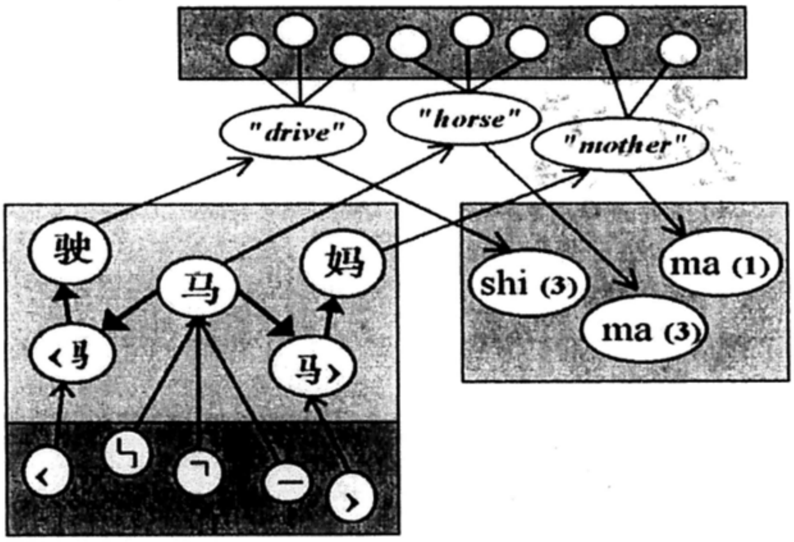

Figure 1 - Multilevel Interaction Activation Model (Taft, 2006).

Actually, even models holding on the view of interactive-activation (e.g., Perfetti et al., 2005; Zhou et al., 1999) also assume that before processing the whole character information, it is the radical that is activated first. This activation is then input into the orthographic system which interacts with phonological and semantic systems. Moreover, one of such interaction models (Perfetti's interactive constituency model) also predicts a complex relationship between simple and compound characters in which the simple characters are used as radicals. Both simple and compound characters are organized in the same character orthographic sub-system, implying occurrence of facilitation and inhibition between compound and simple characters. The pattern of facilitation and inhibition depends on connection parameters that reflect the consistency and validity of radical versions of simple characters and compounds applied to phonological and meaning subsystems. However, in these interactive models, the relative importance and the relationship between position-free and position-specific radicals have not been mentioned. In fact, many points proposed in these models, especially for issues regarding the time course of character processing, are still being debated. Next, we try to summarize the existing findings about the time course of orthographic processing in Chinese character recognition.

1.2.5 The time courses for the effects of different levels of orthographic information

With reference to the time course of orthographic processing, prior research in visual character recognition was mainly conducted along three directions. The first compared orthographic processing directly with phonological and/or semantic processing (e.g., Chen, Flores d' Arcais, & Cheung, 1995; Chen & Shu, 2001; Liu, Perfetti, & Hart, 2003; Perfetti & Zhang, 1995; Tan, Hoosain, & Peng, 1995; Wong & Chen, 2000; Zhou & Marslen-Wilson, 1999c). In this set of studies, the priming paradigm was often used and evidence showed that the orthographic effects emerged earlier than phonological and semantic processing and, in fact, it was within the initial phase of visual character processing.

The second set tested whether the direction of activation was from radical-to-character or the reverse. With regard to this issue, there was evidence showing that processing of the radical was earlier than that of the whole character (e.g., He et al., 2006; Hsu et al., 2009; Lee et al., 2004; Lee et al., 2007; Liu et al., 2003; Yeh & Li, 2004). These findings provided empirical support for models holding on the view of radical-based inputs (Perfetti et al., 2005; Taft, 2006). However, there was also the opposite evidence supporting that the primary direction of activation was from character to radical rather than the opposite (e.g., Chen, 1984, 1987; Liu, Wu, Sue, & Chen, 2006). In addition, some researchers argued that whether it was from radical-to-character or the reverse might depend on the familiarity of a character (e.g., Peng & Wang, 1997; She & Zhang, 1997). High frequency characters might be processed holistically without retrieval of radicals. To explore the activation direction between radicals and characters, previous studies are often conducted from two aspects. A few studies compare the time points between character and radical processing directly (e.g., Chen, 1984, 1987; Liu et al., 2006; Yeh & Li, 2004). Most research explores this issue through manipulating radical information to examine whether these manipulations could evoke change of some earlier ERP (event-related potential) components which are well-known to reflect the processing before retrieval of the whole character information (e.g., He et al., 2006; Hsu et al., 2009; Lee et al., 2004; Lee et al., 2007; Liu et al., 2003).

The last set was to explore the time course for processing of position-specific and position-free radicals. Though Taft (2006) predicted the activation was from position-free radicals to position-specific radicals, the findings of the only relevant research, conducted by Lin, Zhao, Weng, and Chen (unpublished manuscript), tended to support the opposite view, i.e. the direction of activation was from position-specific radicals to position-free radicals.

1.2.6 Summary of the current findings

In sum, prior studies on Chinese have indeed provided some basic information about orthographic processing in visual character recognition. First, it was shown that a radical's semantic/phonetic combinability could influence character processing. Second, researchers didn't know the reasons for the inconsistent findings across different studies, but available results at least indicate that both position-free and position-specific radical information could exert influence on character recognition in some particular situations. Besides, when a radical itself was a legal simple character, the orthographic information of its character version could facilitate the compound character processing when the priming paradigm was used. Finally, no matter whether a radical's semantic/phonetic combinability was manipulated or a character's structural information was manipulated, the studies have provided evidence of the early orthographic activation in Chinese character recognition, and such activation occurred before characters' phonological and semantic processing (e.g., Chen & Shu, 2001; Hsu et al., 2009; Lee et al., 2004; Lee et al., 2007; Liu et al., 2003).

Without any doubt, these findings on Chinese character recognition have provided some important information to enhance our understanding of Chinese orthographic processing. But, note that the available findings are far from clear enough to finally crack the orthographic codes in Chinese character recognition. In fact, there are still many unsettled issues regarding the effects for different levels of orthographic information in Chinese.

Chapter 2

Issues in Debate

2.1 Radical representation: position-free or position-specific

Findings on whether radicals are represented with positional information have been inconsistent in previous studies. Some research found strong positional constraints on radicals (e.g., Ding et al., 2004; Taft et al., 1999, 2000; Taft & Zhu, 1997), while some others emphasized the importance of position-free radicals in character recognition (e.g., Tsang & Chen, 2009; Yeh & Li, 2002). Combining prior findings with their results, Tsang and Chen (2009) proposed one possible reason for the inconsistency in views on the effects of radical positions, that is, the composition of materials. Materials in the studies showing strong positional effects usually contained illegal characters as fillers. In contrast, studies not employing such materials showed the significant effects of position-free radicals instead of position-specific radicals (e.g., Lai & Huang, 1988; Li & Chen, 1999a; Tsang & Chen, 2009; Yeh & Li, 2002). Why is composition of materials so important to reveal the radical position effects? Often, illegal characters are generated by violating one or some of Chinese orthographic rules. As argued by Tsang and Chen, this may be because the whole setup in studies employing illegal characters sensitizes participants to any features that could effectively distinguish legal lexical items from illegal ones. One such useful feature might be the radical position and it is possible that participants in the LDT rely heavily on it once they realize the structure of illegal characters. On the contrary, when no such illegal characters are involved, participants will not weigh positional information strongly during character processing because there is no contrast coming from illegal characters any more. This then leads to the report that position-free radicals become the critical information in Chinese character recognition. In other words, the use of positional information is more strategic than automatic.

However, regretfully, it is just a hypothesis that the material composition could influence the effect of radical positions. Actually, there is no direct evidence for this. Besides, one thing that deserves to be noted is that when illegal characters were used as fillers, the accompanying task was always the LDT in previous studies. Since demand of the LDT itself would attract participants' attention to the structure of a character, it possibly still has the ability to enlarge the effects of radical positions on character recognition. As the structural information is useful to discriminate illegal characters from real ones, more attention may be paid to radical positions in order to make a right and/or fast decision. Thus, it is not clear whether the strong positional effects are only due to the composition of materials or just because of the demand of the LDT. To explore this issue is important in that it could reveal real reasons for the strong effects of radical positions in character recognition and finally enhances development of models of orthographic processing in Chinese.

2.2 The nature and the time point for the effects of a radical's simple character information on compound character recognition

Some theories have been proposed about the relationship between simple and compound characters in which the simple character is used as a radical (Perfetti & Tan, 1999; Zhou & Marslen-Wilson, 1999b). But only a few studies have been conducted on this issue and, in these studies, only the priming paradigm has been used (Ding et al., 2004; Liu et al., 2006). However, in order to finally reveal the nature of the effects of a radical's simple character version on compound character processing, we need to conduct more studies with a variety of paradigms. In addition, as a technique with high temporal resolution, the wide usages of ERPs make us consider when and how the radical's simple character information affects the compound character processing and this has not been answered in previous studies. Finally, with reference to the relationship between representations of a simple character and its radical version, it is still an open question whether they share the same one position-free "simple character" representation or not (Perfetti et al., 2005; Taft, 2006).

2.3 The time course for the effects of different levels of orthographic information

Though Taft (2006) has described the time sequence for the effects of the different levels of orthographic information in visual character recognition, many issues related to this time course have not been settled as yet. In fact, available evidence could only conclude an early orthographic activation in reading Chinese characters, and this activation occurs before both phonological and semantic processing of those characters (e.g., Chen & Shu, 2001; Lee et al., 2007; Liu et al., 2003). With regard to the time course within the orthographic system itself, many issues are yet to be resolved.

First, it is not clear whether orthographic activation is from character to radical or the reverse (e.g., Liu et al., 2006; Yeh & Li, 2004). Second, given both position-free and position-specific radicals have their own representations, as assumed in Taft (2006), there is still no consistency about the issue regarding the direction of activation. According to Taft's model (Taft, 2006), the activation direction should be from position-free radicals to position-specific radicals. But the findings of Lin et al. (unpublished manuscript) tended to support the opposite view, i.e. the activation is from position-specific radicals to position-free radicals. Using ERP technique, Lin et al. found that processing of position-specific radicals occurred almost 100 ms before position-free radicals. However, it should be noted that these findings were obtained by observing and comparing the radical effects in processing of non-characters and pseudo-characters. In this design, radicals embedded in illegal characters have been separated from real characters and, more importantly, effects of radicals were investigated under this separating condition. Consequently, it is really unclear whether the findings of Lin et al. could be applied in daily life situations when radicals are embedded in real characters. Finally, given the possibility that the composition of materials and/or tasks might influence the effects of radical's position, this then induces the question regarding the time course for radical position effects in character recognition, that is, whether the time course could remain the same across the experiments with different tasks and/or different materials?

Chapter 3

The Present Study

In view of the above mentioned questions, the present research was designed to examine: (1) the possible influence of stimulus composition and nature of task in the radical processing, including its time courses; (2) the nature and the time point of the effect of simple characters during processing of compound characters in which simple characters were used as radicals; (3) the possible direction of the orthographic activation between characters and radicals; (4) the possible time sequence for the effects of position-free and position-specific radicals and whether such time sequence was the task specific mechanism.

A total of four experiments were conducted in the present research. The first two (Experiments 1 and 2) were behavioral experiments conducted to investigate effects of different kinds of radicals on visual character recognition as well as the influence of the task and the composition of materials on these effects. In Experiment 1, the LDT was used. As a classical task, lexical decision could provide an opportunity to compare the current results with prior ones. But, note that, lexical decision itself could possibly enlarge the effects of position-specific radicals. Hence, it is necessary to employ another task to verify whether the effects of position-specific radicals are still the same, after avoiding the influence of the LDT. Moreover, the radical effects could be observed only when characters are processed consciously in the LDT. In order to investigate the effects of radical information by observing the character processing under the automatic operation conditions, an implicit task, the position decision task (PDT), was used in Experiment 2. The importance of this implicit task (i.e. PDT) is not only to ensure character processing is not affected by a linguistic task, but also to avoid the explicit processes of stimuli. Besides, within each of these two experiments, there were sets of sub-experiments, among which the types of fillers had been varied systematically. Through this design, effects of stimulus composition on radical processing could be investigated by comparing the results of that particular set of sub-experiments.

Following the first two experiments, Experiments 3 and 4 were consequently conducted to examine the roles of different kinds of radical information in Chinese character recognition. Moreover, if these different kinds of radical information could indeed influence character processing, then we wanted to investigate how these kinds of radical information modulated ERPs generated during visual character recognition, so as to reveal the relative time courses in character and radical processing, such as whether the direction of activation is from position-free to position-specific radicals, as proposed by Taft (2006). The ERP technique is particularly useful for the current purpose because it is a technique with high temporal resolution, which allows the continuous monitoring of radical effects. Again, LDT was used in Experiment 3 and PDT was used in Experiment 4. Then, by comparing Experiments 3 and 4, whether the task could influence the effects of radicals on character recognition, and whether it could influence time courses of these effects could be investigated. Moreover, in Experiment 4, the type of fillers had been varied so that influence of stimulus composition on the radical effects, as well as on the time course for their effects, could be further examined.

To be specific, in all of these experiments, we manipulated three kinds of frequencies of radicals: radical frequency (RF), position-specific radical frequency (RPF), and the frequency of a radical as a character (RCF). The RF refers to the number of characters that contain a particular radical no matter which position it is in the character and which function it takes, whereas RPF is the number of characters that contain a particular radical in a particular position, regardless of its function. For instance, 巾 occurs as a radical in 80 different characters; however, when it is used specially as a right-hand radical, 巾 appears only in 1 character. Thus, the RF of radical "巾" is 80 characters, whereas its RPF in right hand is 1 character.

Basically, these two kinds of type frequencies (i.e., RF and RPF) could be assumed to correspond to the orthographic neighborhood size in alphabetic languages, to some extent. For instance, the definition of orthographic neighborhood size is the number of words that are formed by changing one letter of the target stimulus while preserving letter positions (Coltheart, Davelaar, Jonasson, & Besner, 1977). Under this definition, letter position is taken into account as an important factor for word recognition. In contrast, in this study, both position-specific and position-free radicals have been taken into account. This is because by comparing the effect of RPF with that of RF, the relative importance of radical position could be examined. Besides, the design of the present study follows the logic in prior studies to investigate the direction of orthographic activation between characters and radicals. That is, we manipulate orthographic information of a radical as a radical, i.e., RF and RPF, and then check whether these manipulations could evoke change of some earlier ERP components which are proved to reflect the processes before processing of the whole characters.

The final radical frequency measured is the RCF. This is a type of token frequency for a radical because when the radical is used as a character in its own right, its character frequency is labeled as the RCF. It indicates how frequently a radical appears when it is used as a character. For example, when used as a character (the meaning is "towel"), 巾 of "帅" has a frequency of 32 per million. Following this design, the possible influence of the information of a radical as a character could be examined during processing of compound characters.

Chapter 4

Experiments

4.1 Experiment 1

Two behavioral experiments were conducted to provide a brief overview of effects of RF, RPF and RCF on character processing, as well as the influence of stimulus composition on these effects in LDT. A similar behavioral study (Taft & Zhu, 1997) was conducted on visual character recognition after manipulating RF and RPF. However, given the limitations of the study of Taft and Zhu (1997), the need to conduct these two experiments was felt in three aspects. First, the study of Taft and Zhu failed to produce the consistent results about the role of RF as compared to Li and Chen (1999b). In Taft and Zhu, no difference was found between the decision times of the characters with high and low RF, whereas in Li and Chen, results showed that the RF could influence character processing, with response to high RF items being faster than to low RF characters.

Besides these controversial results, another limitation of Taft and Zhu (1997) was that the manipulation of RPF might have been confounded by RF. This is because the method to count the radical position frequency in previous document (Chinese radical position frequency dictionary, 1984) is based on the radical's emergence order in a character, but it does not take its exact position into account. For instance, as a right hand radical, the radical position frequency of "巾" is one character but according to the method based on the radical's emergence order, as a right hand radical, RPF of "巾" may be two, but not one. This is because such a calculation includes not only the two-radicals character with horizontal structure when "巾" is in the right position, such as "帅", but also the one with vertical structure when "巾" emerges in the bottom position, such as "吊". In these two characters, the writing order of the radical "巾" is the same, as the second component of characters. So adopting this incorrect method to calculate the RPF may be responsible for the failure to discriminate effects of the RPF from those of the RF in visual character recognition.

The final and the most important one is that in the present experiments, the composition of materials has been taken into account. This is because it may be the critical factor to cause inconsistency in effects of radicals across different studies (e.g., Li & Chen, 1999b; Taft & Zhu, 1997) as discussed in Tsang and Chen (2009). However, regretfully, no research has been conducted to follow this hypothesis and actually, these two experiments are among the first to investigate this issue. As discussed before, the reason under the effects of stimulus composition on radical processing may be due to the different degrees at which different kinds of fillers sensitize participants to the information about the radical position. The more salient the radical position information in the fillers is, the stronger the radical position effects are.

In order to examine this hypothesis, two kinds of illegal characters varied in salience of radical positions were manipulated in the current experiments. Experiment 1a used non-characters as fillers, whereas Experiment 1b adopted pseudo-characters as fillers. Non-characters were constructed by reversing the radicals in real characters. In other words, the non-characters would be the real ones, once we change the left radical to the right and the right radical to the left in horizontal structures, or when we change the bottom to the upper and the upper to the bottom in vertical structures (see Figure 2). Therefore, all the radical positions in non-characters were reverse of their positions in real characters. In contrast, pseudo-characters were constructed by arranging the real radicals from existing characters into illegal combinations which do not exist in the Chinese corpus, but the radicals occupied their normal positions (see

Figure 3). Actually, the pseudo-characters did not violate any orthographic property or rule of the Chinese language.

Figure 2- Example of the non-character.

Figure 3- Example of the pseudo-character.

Therefore, if the composition of materials is the critical factor to influence radical effects through modulating the salience of radical positions, significant RPF (but not RF) effects would be found in Experiment 1a, because participants may perhaps only need to rely on radical position information to make a decision, once they realize the composition of non-characters. In contrast, when participants are required to distinguish pseudo-characters from real characters, because pseudo-characters don't violate any obvious orthographic rule or property such as radical's form or position, the difficulty to distinguish pseudo-characters from real characters may induce any possibly useful information that could guide the decision may be retrieved. Therefore, both position-free and position-specific radicals have possibilities to be activated and then affect character processing. Consequently, we would observe both RF and RPF effects in Experiment 1b.

Besides, In some prior studies conducted on alphabetic languages (e.g., Duñabeitia, Perea, & Carreiras, 2007), the constituent (it is a word) frequency could facilitate compound word processing: compound words containing high frequency constituents had faster RT as compared to those with low frequency constituents. In Chinese character recognition, we hypothesize that a similar result would be found. So we would observe a significant effect of RCF on compound character processing.

4.1.1 General Method

In Experiments 1a and 1b reported here, the same real characters, apparatus, overall design, and procedures were employed. These experiments differed only in fillers chosen. A general method for these two experiments, including details of the fillers, is described in this section.

4.1.1.1 Subjects

Forty eight native-Mandarin speakers (26 females and 22 males; aged between 20 and 25 years, with mean age of 22.4 years) from South China Normal University were paid to participate in these two experiments (24 in each experiment). All participants had normal or corrected-to-normal vision.

4.1.1.2 Materials

To avoid confusion between RPF and RF, an online database of Chinese characters (ISO 10646) was adopted to establish experiment materials. After inputting a radical into this database, all characters that contained this specific radical were displayed; the number of displayed characters was considered as the RF of that radical. Furthermore, among these characters, the number of characters in which that radical is in a specific position such as left/ right/ upper/ bottom was marked as its RPF in the corresponding position.

Since three pairs of conditions were included, as described in the introduction, six sets of compound characters were designed (see Appendix A). For each pair of conditions, items were designed in pairs, and only one of the radical frequency measures varied while the other two were held constant and matching the target character frequency (CF), as well as the stroke number (SN). Table 1 shows the basic information of experimental variable and the other controlling variables in each pair of conditions.

Table 1- Stoke number (SN), Character frequency (CF), Position-specific radical frequency (RPF), Radical frequency (RF), and Radical's simple character frequency (RCF) in each experimental condition.

		SN	CF	RCF	RF	RPF	SELECTION CRITERIA
Pair 1	HRPF	8.5	46.8	245.6	45.8	**28.4**	14=>X<=74
	LRPF	8.4	48.2	244.6	46.9	**4.2**	1=>X<=9
Pair 2	HRF	8.1	25.7	268	**113.8**	5.9	60=>X<=178
	LRF	8.5	24.8	263.2	**15.9**	5.8	4=>X<=34
Pair 3	HRCF	8.6	36.6	**2674.1**	22.9	5.9	272=>X<=21884
	LRCF	8.8	34.8	**66.4**	23.5	6.9	11=>X<=132

Note: H-high; L-low; Selection criteria are suitable for the experimental variable in each condition.

For instance, between the two conditions HRPF and LRPF, only the RPF was different. According to the database of ISO 10646, RPF was larger than 14 characters for the HRPF condition, and smaller than 9 characters for the LRPF condition. A paired t-test revealed that the difference between HRPF and LRPF items was significant, $t(17) = 6.25$, $p < .001$. Besides, the HRPF and LRPF items were matched on RCF, RF, CF and SN. Statistical results revealed no significant difference between HRPF and LRPF items for any of the controlling factors (*ps* > .4). Because it proved difficult to find pairs of characters that were matched on all relevant factors, only 18 pairs were included.

Similarly, HRF and LRF conditions varied only on RF. According to the database of ISO 10646, RF was always larger than 60 characters for HRF condition, and was always smaller than 34 for LRF condition. The difference between them was significant, $t(19) = 10.55$, $p < .001$. HRF and LRF items were approximately matched overall on RPF, RCF, CF and SN. Again, paired *t*-tests did not reveal any significant difference between the two levels of any controlling variable (*ps* > .2). In total, 20 pairs of compound characters were found to satisfy the entire requirements.

Finally, the situation was the same for the last two conditions, HRCF and LRCF. Only RCF was different between them. According to Modern Chinese frequency dictionary (1990), in the HRCF condition, RCF was always larger than 272 per million, while in the LRCF condition, it was always smaller than 132 per million. The difference was significant, $t(19) = 2.2$, $p < .05$. The HRCF and LRCF items were approximately matched on RPF, RF, CF and SN. Paired *t*-tests did not reveal any significant difference between the two levels of any controlling factor (*ps* > .3). Twenty pairs of compound characters were found to satisfy all the requirements.

Therefore, totally 58 pairs of compound characters were included. Almost all the characters were composed of two radicals, 88% of which were horizontally structured and 12% were vertically structured. Besides, in order to counterbalance the yes and the no responses in LDT, a total of 116 non-characters (Experiment 1a) or pseudo-characters (Experiment 1b) were used. Again, 88% of non-characters or pseudo-characters were of horizontal structure, and 12% were of vertical structure. All stimuli, including non-characters or pseudo-characters, were printed in simple Kai-Ti font, 1.5 cm in both length and width for each stimulus. Characters subtended a visual angle of about 1.2 degrees around the fixation.

4.1.1.3 Procedure

Each trial began with a fixation point "+" at the centre of the screen for 500 ms, followed by a blank that also lasted for 500 ms. Then a stimulus (a character or an illegal character) appeared on the screen until the decision button was pressed. Participants were asked to indicate whether or not the stimulus displayed here was a real character and to respond as quickly and accurately as possible. Stimuli were randomly divided into 8 blocks, each containing 29 items. Each item was randomly presented across all blocks. Besides, two versions were constructed. One version made the key "f" to correspond to "Yes" and "j" to "No", whereas, the other version allocated keys in the reverse order.

4.1.2 Results of Experiment 1a

Mean RT and correct rejection rates for non-characters were 606 ms (SD = 193) and 96.4% (SD = 0.19), respectively. Table 2 displays mean RT and accuracy for characters in the three pairs of conditions. Paired *t*-tests were performed to compare mean RT between each pair of conditions. Although items in the HRCF condition had a tendency to be faster than the characters in the LRCF condition, it proved not significant in both by-subject (t_1) and by-item analyses (t_2), t_1 (23) = 1.34, $p > .05$; t_2 (19) = 1.46, $p > .05$. Similarly, no significant difference was found between HRF and LRF (both *t*s < 1). However, the character decision time for HRPF items was faster than LRPF items, t_1 (23) = 2.33, $p < .05$; t_2 (17) = 1.87, $p = .078$.

In addition, the paired *t*-tests performed on accuracy showed a higher degree of accuracy in the HRPF condition than in the LRPF condition, t_1 (23) = 2.63, $p < .05$; t_2 (17) =1.87, $p = .079$. Apart from this, no other significant results were found in the accuracy analyses (*p*s > .05). These results indicate that when non-characters are used as fillers, it seems that only the radical position information is available for readers to discriminate non-characters from real characters.

Table 2- Mean RTs (ms) and accuracy rates for the characters of Experiment 1a in three pairs of conditions.

	Pair 1		Pair 2		Pair 3	
Condition	HRPF	LRPF	HRF	LRF	HRCF	LRCF
RT	563 (61)	587 (80)	566 (70)	569 (73)	562 (71)	580 (86)
Accuracy	.988 (.028)	.961 (.058)	.981 (.029)	.965 (.048)	.975 (.047)	.977 (.036)

Note: Standard deviations are shown in parentheses.

4.1.3 Results of Experiment 1b

Mean RT and correct rejection rates for pseudo-characters were 727 ms (SD = 264) and 83.1% (SD = 0.37), respectively. Table 3 contains mean RT and accuracy for characters in the three pairs of conditions. Paired *t*-tests were performed to compare the mean RT between each pair of conditions. The results showed that HRCF items were associated with the faster character decision response (than the LRCF items), but did not reach significance by items, t_1 (23) = 3.58, $p < .05$, t_2 (19) = 1.74, $p > .05$. As anticipated, the RT for characters in the HRF condition was faster than that in the LRF condition, t_1 (23) = 2.59, $p < .05$; t_2 (19) = 2.50, $p < .05$. Again, the faster RT was found in the HRPF condition when it was compared to the LRPF condition, t_1 (23) = 4.57, $p < .001$; t_2 (17) = 2.49, $p < .05$.

Besides, separate paired *t*-tests were carried out on accuracy which revealed a significantly higher degree of accuracy in the HRPF condition over the LRPF condition, t_1 (23) = 5.37, $p < .001$; t_2 (17) = 3.15, $p < .01$. No other significant effects were found among the other two pairs of conditions in analyses of accuracy (*ps* > .05). These results indicate both the position-free radical and the position-specific radical information could exert influence on character processing, when pseudo-characters are used as fillers.

Table 3- Mean RTs (ms) and accuracy rates for the characters of Experiment 1b in three pairs of conditions.

	Pair 1		Pair 2		Pair 3	
Condition	HRPF	LRPF	HRF	LRF	HRCF	LRCF
RT	600 (73)	648 (109)	621 (75)	651 (97)	617 (79)	644 (89)
Accuracy	.988 (.023)	.921 (.069)	.973 (.042)	.952 (.070)	.971 (.049)	.952 (.058)

Note: Standard deviations are shown in parentheses.

4.1.4 Discussion

After avoiding confusion between RF and RPF, the results confirmed the validity of radical position effects observed in Taft et al. (e.g., Taft et al., 2000; Taft & Zhu, 1997). If a compound character shared a radical with many other characters while preserving its position, it would be recognized more quickly than one sharing a radical in a particular position with a few characters. But, the radical position had not been considered; the radical effect was impacted by the composition of materials. The processing of a compound character sharing a radical with many neighbors, regardless of its position, was facilitated only when participants distinguished real characters from a set of pseudo-characters, but not from non-characters.

The fact that the composition of materials can influence the RF effect is compatible with the comparisons across studies in which it was significant when pseudo-characters were involved as fillers (Li & Chen, 1999b), and not significant when non-characters were used (Taft & Zhu, 1997). As our hypothesis, one of the possible reasons for these results is that the structure of non-characters is different from that of pseudo-characters. In non-characters, the information that radical position is wrong will bias participants to pay more attention to radical position. Since it is so effective whenever participants use it, it may become the only index at last to guide the decision. Thus, other orthographic information such as radical form and radical combination would no longer be necessary. In contrast, when pseudo-characters are involved, the position of a radical is never the most useful information to guide the decision, because it is not the critical rule that has been broken in pseudo-characters. Given that pseudo-characters are so similar to real ones, any possibly useful information (e.g., radical's combination, form, and position or even the character's meaning) may be retrieved so as to make a right decision.

But, note that there is still another possibility for the different effects of RF between different compositions of materials found here. It may be due to the different processing times triggered by different kinds of fillers in LDT. Relative to non-characters, pseudo-characters are much more similar to real characters, and consequently participants may need more time to discriminate pseudo-characters from real characters in making a lexical decision. This could be shown in the overall RTs for all the stimuli in Experiments 1a and 1b. For instance, the overall mean RT was 588 ms in Experiment 1a, whereas it was 683 ms in Experiment 1b (the difference was significant, $t\,(23) = 3.26$, $p < .01$). Given that the longer processing time indicates the deeper level of processing, it is possible that only when the characters are processed deeply, position-free radical information could be retrieved to exert influence.

However, since LDT must be accompanied by illegal characters and the composition of illegal characters is sure to be an important factor to influence the decision time, the design in Experiment 1 could not reveal which hypothesis is true. Thus, if we want to find the real reason for the effects of stimulus composition on radical processing, further experiments with tasks which could not be influenced by the composition of illegal characters should be conducted.

Moreover, from another point of view, the present results appear to show that the effects of position-specific radicals are stable in LDT regardless of the material composition. However, one thing that deserves to be noted is that either non-characters or pseudo-characters are the illegal characters constructed by destroying one or some of orthographic rules. It may be that once there are illegal characters, effects of position-specific radicals would be significant. The effect of illegal characters on radical position could be attributed to their construction, which is generated by destroying some kinds of orthographic rules. So, as the most useful orthographic information, it is not surprising that more attention may have been paid to radical positions. But note that because in this experiment, LDT and illegal characters are combined together, we can not extract the effects of illegal characters from those of the LDT. The LDT effect could be attributed to the demand itself, in the process of which the character orthographic rules have actually been emphasized greatly. Actually, prior studies also had a similar problem (e.g., Ding et al., 2004; Taft et al., 1999; Taft & Zhu, 1997); when illegal characters were used as fillers, the accompanying task was always the lexical decision. Thus, it is not clear whether the strong position effects on radicals are only due to participants' awareness of the composition of illegal characters or just because of the demand of the LTD. Experiment 2 was consequently conducted to test this issue by employing another task, the position decision task (PDT), while keeping the composition of materials the same as in Experiment 1 or changing it to another kind.

4.2 Experiment 2

Similar to Experiment 1, non-characters were used as fillers in Experiment 2a, and pseudo-characters were involved in Experiment 2b. The results of these two experiments would provide a contrast for those of the LDT so that the effects of task could be investigated. In Experiment 2c, geometric figures instead of illegal characters were used as fillers. Geometric figures used here provide an opportunity to further examine different kinds of radical effects in the situation when there are no LDT and no illegal characters. Experiment 2c is important in that when using fillers from another category, geometric figures, the issue whether the effects of position-specific radicals are triggered by illegal characters could be investigated through comparison between the experiments with and without illegal characters.

4.2.1 General Method

In Experiments 2a-2c reported here, the same real characters, apparatus, overall design, and procedures were employed. These experiments differed only in fillers chosen. A general method for these three experiments is described in this section.

4.2.1.1 Subjects

Seventy two native-Mandarin speakers (42 females and 30 males; aged between 20 and 26 years, with mean age of about 23 years) from South China Normal University were paid to participate in these experiments (24 in each experiment). All participants had normal or corrected-to-normal vision. None of them had participated in the previous experiments.

4.2.1.2 Materials

The same real characters as in Experiment 1 were used in this experiment also. Besides, non-characters, pseudo-characters, and geometric pictures were used as fillers in Experiments 2a, 2b and 2c, respectively. Non-characters and pseudo-characters were the same as in Experiments 1a and 1b. The geometric figures were composed of different lines with various lengths, directions, and etc. (see Figure 4). The complexity of geometric pictures corresponded to that of characters, matching the number of lines in a picture with the number of strokes in a character. For instance, if there was one character with 4 strokes, there would be one geometric picture with 4 lines. The size of all stimuli including real characters and fillers was around 1.9 cm in both length and width. Stimuli subtended a visual angle of about 1.4 degrees around the fixation. All real characters, non-characters and pseudo-characters were printed in simple Kai-Ti font.

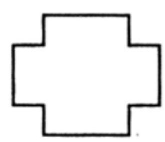

Figure 4- Example of the geometric figure

4.2.1.3 Procedure

At the very beginning, a cross was displayed at the center of the screen for 500 ms. Around 500 ms later, a stimulus (a character or a filler) was presented for 200 ms. It wasn't at the center of the screen, but slightly to the right or the left. The misaligned stimulus subtended a visual angle around the central fixation which did not exceed 2 degrees. So it was still within the central vision field. Immediately after its offset, a mask with the size large enough to cover all positions of stimuli appeared for a maximum of 2000 ms. Participants were required to judge whether the target stimulus appeared on the right or the left, relative to the central fixation, and respond as accurately and quickly as possible when they confirmed the position.

There were two versions of stimuli. The only difference between these two versions was the position of stimuli. If the stimulus was presented on the left position in one version, it would be on the right in the other. Each subject was tested on only one version.

4.2.2 Results of Experiment 2a

Mean RT and accuracy for non-characters were 359 ms (SD = 110) and 97.5% (SD = 0.16), respectively. Table 4 displays mean RT and accuracy for characters in each pair of conditions. Paired *t*-tests did not reveal any significant difference between each pair of conditions, *ps* > .1, indicating that in spite of the same materials as in Experiment 1a having been employed, the effects of RPF were not significant any more when the PDT was used.

Table 4- Mean RTs (ms) and accuracy rates for the characters of Experiment 2a in three pairs of conditions.

	Pair 1		Pair 2		Pair 3	
	HRPF	LRPF	HRF	LRF	HRCF	LRCF
RT	345 (53)	341 (56)	349 (57)	348 (51)	349 (56)	351 (62)
Accuracy	.968 (.059)	.975 (.052)	.985 (.031)	.990 (.033)	.977 (.047)	.985 (.023)

Note: Standard deviations are shown in parentheses.

4.2.3 Results of Experiment 2b

Mean RT and accuracy for pseudo-characters were 420 ms (SD = 140) and 97.1% (SD = 0.17), respectively. Table 5 displays mean RT and accuracy for characters in each pair of conditions. Paired *t*-tests revealed the HRF items were associated with the slower RT, as compared to the LRF items, t_1 (23) = 2.57, $p < .05$, t_2 (19) = 3.08, $p < .01$. Apart from this, no other significant effects were found (*ps* > .1). These results suggest that in a PDT, when pseudo-characters are used as fillers, only RF could exert influence on character recognition.

Table 5- Mean RTs (ms) and accuracy rates for the characters of Experiment 2b in three pairs of conditions.

	Pair 1		Pair 2		Pair 3	
	HRPF	LRPF	HRF	LRF	HRCF	LRCF
RT	398 (76)	396 (66)	407 (76)	394 (69)	405 (71)	404 (73)
Accuracy	.965 (.059)	.972 (.046)	.975 (.033)	.977 (.039)	.977 (.053)	.975 (.036)

Note: Standard deviations are shown in parentheses.

4.2.4 Results of Experiment 2c

Table 6- Mean RTs (ms) and accuracy rates for the characters of Experiment 2c in three pairs of conditions.

	Pair 1		Pair 2		Pair 3	
Condition	HRCF	LRCF	HRF	LRF	HRPF	LRPF
RT	378 (70)	374 (62)	376 (74)	372 (69)	370 (72)	368 (63)
Accuracy	.980 (.036)	.974 (.033)	.987 (.027)	.976 (.033)	.973 (.041)	.978 (.036)

Note: Standard deviations are shown in parentheses.

Mean RT and accuracy for geometric figures were 393 ms (SD = 111) and 97.8% (SD = 0.15), respectively. Table 6 displays mean RT and accuracy for characters in each pair of conditions. Paired *t*-tests performed on each pair of conditions did not reveal any significant effect (*ps* > .1), indicating that all kinds of radical information could not affect character decision when geometric figures were used as fillers in the PDT.

4.2.5 Discussion

When changing the LDT to the PDT, the fact that the effect of RPF was no longer significant seems to indicate that only containing illegal characters is not enough to evoke the effect of radical position: it should be combined with LDT to exert influence on character processing. However, the effect of position-free radicals was relatively stable across these two tasks. Both in the LDT and PDT, when pseudo-characters were used as fillers, it would play a role in character recognition (Experiments 1b and 2b). In addition, the RCF effect was still not significant in this experiment, indicating that the frequency of a radical when it was used as a simple character might not play a role in processing of compound characters in PDT.

Firstly, based on current results, one thing that seems to be clear is that the different effects of RF between Experiments 1a and 1b could not be attributed to the different processing times involved. The reason lies in the significant effect of RF in Experiment 2b even when the overall mean RT was quite short (411 ms). Actually, it was significantly smaller than 588 ms of Experiment 1a (t (23) = 8.63, $p < .001$), in which it did not reveal any significant effect of RF. So the comparison between Experiments 1a and 2b indicates that the processing time is not the critical factor to induce the different effects of position-free radicals between Experiments 1a and 1b.

Secondly, the finding that the role of RPF could be affected by the task provides a possible reason for the position-specific radical effects being so robust in studies of Taft and his colleagues, (e.g., Ding et al., 2004; Taft & Zhu, 1997). This is because the task in these studies was always the LDT. Once another task such as illusion report in Tsang and Chen (2009), or visual search in Yeh and Li (2002) or the PDT in this research was employed, the position-free radicals became the most important information for character processing.

In addition, it seems to be curious that in Experiment 1 (LDT) and Experiment 2 (PDT), patterns of neighborhood size effects (RF or RPF) were found to be oppose of each other. In Experiment 1, once the effect of RF or RPF was significant, mean RT was faster for larger neighborhood characters (HRF or HRPF) than for smaller ones (LRF or LRPF). On the contrary, in Experiment 2, RT was faster for characters with LRF than for those with HRF.

In fact, the facilitation effect of neighborhood size for characters/words in LDT is well-documented: it is robust (e.g., Carreiras, Perea, & Grainger, 1997; Grainger & Jacobs, 1996; Holcomb, Grainger, & O'Rourke, 2002; Li & Chen, 1999b; Taft et al., 2000; Taft & Zhu, 1997). Prior researchers have usually used the interactive activation model (Rumelhart & McCelland, 1982) to interpret it, from the viewpoint of global lexical activation of the current character and its neighbors. Given the assumption that characters with many neighbors generate high levels of global lexical activation, in LDT, participants can use the extra activity associated with partial activation of all items in the neighborhood to speed up their "Yes" response. For small neighborhoods (LRF and LRPF), less activity in the neighborhood translates into slower RTs because of lower overall lexical activity.

However, regarding the question whether the inhibitory effect on RTs in PDT is due to the same mechanism as the facilitation effect on RTs in LDT, we can't answer it now. Actually, in numerous ERP studies (e.g., Barber, Vergara, & Carreiras, 2004; Carreiras, Vergara, & Barber, 2005; Holcomb et al., 2002; Hsu et al., 2009; Lee et al., 2004; Lee et al., 2007; Taler & Phillips, 2007), it has been shown that the neighborhood size could exert the opposite influence on different ERP components in visual word or character recognition. In other words, the behavioral facilitation and inhabitation might have shown on the ERP waveforms by affecting different components. So given the complex processes determining the RTs, we go back to the mechanism causing the inhibitory effect in the corresponding session of ERP experiments.

Nevertheless, given that RT is a kind of dependent variables that is easily affected by strategic or decision-related factors (Holcomb et al., 2002), any conclusion based on the current findings of these two experiments should be taken with caution. Therefore, before any further discussion, we should first confirm the validity of the results obtained so far when another more sensitive dependent variable is used. Hence, in the following experiments, ERPs, instead of RTs, were recorded, when participants performed lexical decisions (Experiment 3), or positions decisions (Experiment 4).

4.3 Experiment 3

Following the first two experiments, the main purpose of Experiment 3 is to further investigate the effects of different kinds of radical information and the time course for these effects in Chinese character processing. Based on previous studies on orthographic processing in visual word recognition (e.g., Chauncey, Holcomb, & Grainger, 2008; Dufau, Grainger, & Holcomb, 2008), three ERP components are particularly relevant to our purpose. The first is P150, which starts as early as 90 ms after stimulus onset and has a posterior scalp distribution. This component has been taken as reflective of the initial orthographic processing of visual features and activation of sublexical units during visual word recognition (Chauncey et al., 2008). Furthermore, Dufau, Grainger, and Holcomb (2008) demonstrated that the size of P150 could be modulated by physical position such that a physical misalignment between the prime and the target reduced the P150 observed. On the other hand, P150 was reported to reflect "operation on relatively abstract information" (Holcomb & Grainger, 2006, p.10). We, therefore, predicted that if a position-specific radical is involved in the initial phase of character recognition, RPF should modulate the size of P150. In contrast, if position is not an important feature in initial activation of radicals, only an RF effect should be obtained.

The second ERP component of relevance is a positive going waveform peaking at around 200 ms after stimulus onset (e.g., Holcomb et al., 2002; Lee et al., 2004; Lee et al., 2007; Liu et al., 2003). Previous studies have shown that this component is sensitive to the number of orthographic neighbors in English (Taler & Phillips, 2007) as well as in Chinese (Hsu et al., 2009). Given that P200 was smaller in case of a radical-sharing prime, rather than an unrelated control prime, preceded the target character (Liu et al., 2003), this component appears to reflect the general ease of orthographic processing at the sublexical level. Following this logic, the fact that characters with large neighborhood size would elicit a smaller P200 is thought to reflect increased levels of overall orthographic activation for stimuli with larger number of neighbors (Hsu et al., 2009).

The final component is N400, which is well-known for its relationship with semantic processing. Among other things, the N400 has been found to correlate with effects of different kinds of subcomponent frequency measures in word or character recognition. On the one hand, in Hsu, Tsai, Lee, and Tzeng (2009), the reduction in P200 in recognizing characters with many neighbors, relative to those with fewer neighbors, was followed by an increase of N400. The authors reasoned that the N400 was elicited probably because of the lexical competition among the partially activated orthographic neighbors (also see Holcomb et al., 2002, for similar arguments). On the other hand, in a recent ERP research (Martínez, Duñabeitia, Laka, & Carreiras, 2009), early positivity (it was similar to P200 effects) and N400 have been found to be sensitive to the effect of constituent (i.e. word) frequency in reading of compound words (words that are composed of two or more free-standing sub-component words): early negativity was increased, and N400 was larger, for low-frequency than high-frequency constituents. The early positivity was interpreted as reflecting that more candidates were triggered by high frequency constituents and the N400 effect was interpreted as associated with differences in facilitation of the whole word semantic integration generated by stimuli of different frequencies.

The behavioral patterns of RF and RPF manipulations in Experiment 1b have shown their effects on Chinese character recognition. Thus, we predict smaller P200 and/or larger N400 are associated more with HRF and HRPF than their own counterparts. However, predicting ERP results of RCF manipulation is not so straightforward. Our behavioral experiments did not reveal significant effect of RCF on Chinese character recognition but that may be because the RT is not sensitive enough to reveal it. Nevertheless, if it could exert effects on ERPs, the HRCF should be found to be associated with a smaller earlier negativity and/or a smaller N400 than the LRCF. But, exactly, which components would be found? It may depend on the starting time points for RCF effects.

In short, by observing sensitivity of P200 and N400 to RPF and RF manipulations, we could draw conclusions about the relative importance of radical position during Chinese character recognition. Besides, by monitoring the relative onsets of these effects, we could test the proposal by Taft (2006) that position-free radicals are activated before position-specific radicals. If this proposal holds, the effect of RF should be associated with an earlier effect such as P150 or a component with an earlier latency.

4.3.1 Method

4.3.1.1 Subjects

Twenty right-handed students (13 females and 7 males, aged between 19 and 23 years, with mean age of 21.6 years) of the Chinese University of Hong Kong participated in the experiment. All had normal or corrected-to-normal vision and were native speakers of Mandarin. None had a history of any psychiatric or neurological disorder. They were paid for their participation. Two of the participants were excluded from the final analysis due to excessive eye movements.

4.3.1.2 Materials

The same materials as in Experiment 1b, including fillers, were employed in the present experiment. However, since at least 40 items in one condition were needed to achieve a reliable result when using the ERP technique, all materials were presented three times. Therefore, there were a total of 60 items for each of the four conditions (HRCF, LRCF, HRF, and LRF), and 54 items for each of the remaining two conditions, HRPF and LRPF.

4.3.1.3 Procedure

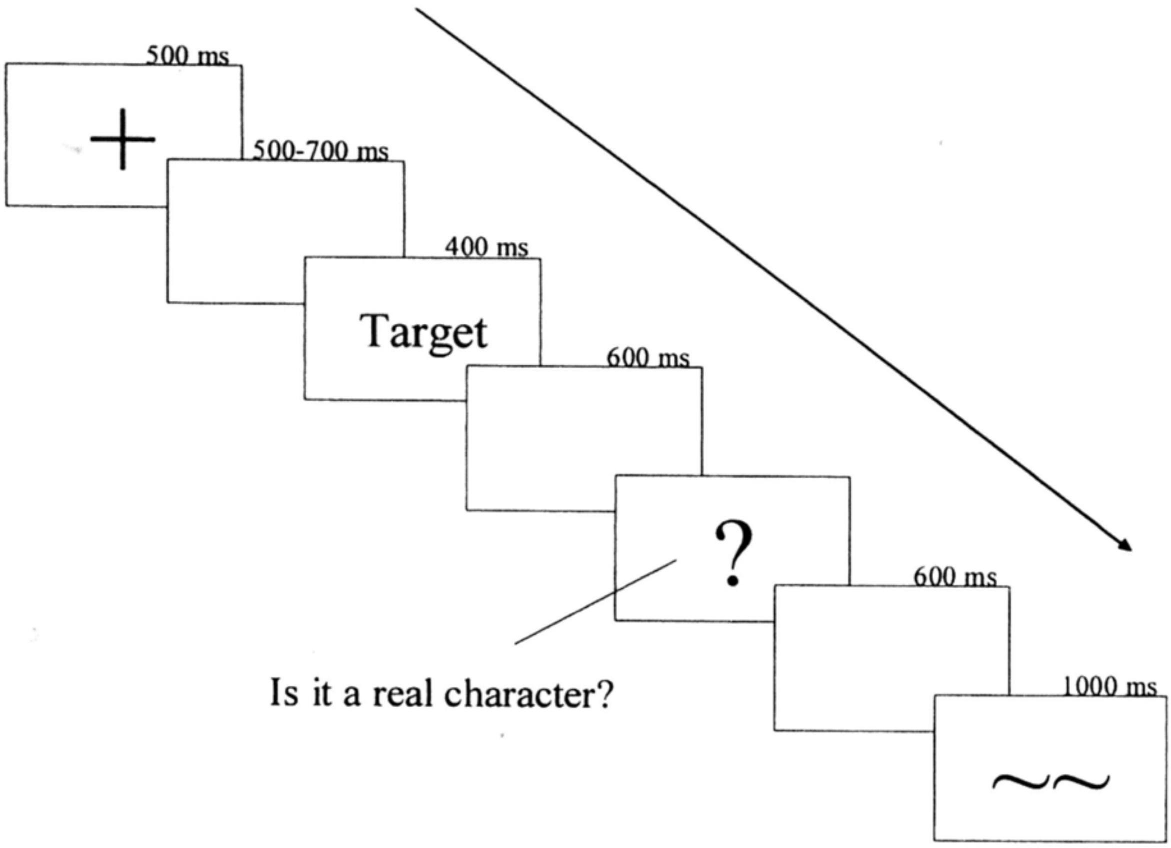

Figure 5- Procedure of Experiment 3.

Participants were tested individually in a sound-attenuating, electrically shielded booth. At the very beginning, participants were seated in a comfortable reclining chair and were asked to sign an agreement to undergo this experiment.

During the experiment, every trial began with a cross presented for about 500 ms at the center of the computer screen for participants to focus on. About 500 to 700 ms after the offset of the cross, a stimulus was presented for 400 ms at the same position. After an interval of 600 ms participants were required to make a judgment whether the stimulus presented here was a real character or not as quickly and accurately as possible once a response symbol "?" appeared on the screen for a maximum time of 2000 ms. After pressing a corresponding key, "f" or "j", a blank was presented for 600 ms, followed by a blink signal "~~" for 1000 ms. During this period, subjects could blink and move their eyes. About 600 ms after it disappeared, the next trial began (see Figure 5). The whole experiment lasted for a total of about 2 hours. Stimuli were randomly divided into 12 blocks, each containing 58 items. Each item was randomly presented across all blocks. Again two versions were adopted, as in Experiment 1.

4.3.1.4 ERP recordings and analyses

ERP data were recorded and analyzed by a 64-channel (Ag-Agcl) Neuroscan version 4.3 system with a common vertex reference and transformed offline to the mean of the activity at the two mastoid processes. The electrooculogram (EOG) was obtained from below versus above the left eye (vertical EOG) and the left versus right lateral orbital rim (horizontal EOG). Electrode impedances were always kept below 5KΩ. The EEG and EOG signals were digitized on-line with a sampling frequency of 1000Hz. EEG recordings were filtered digitally with a 0.05 to 30 Hz band pass offline.

ERPs were computed for each subject over an epoch from 100 ms before to 700 ms after the target character onset. Epochs contaminated by ocular artifacts or other movements' artifacts were excluded from further analyses by the criteria of 70 μV. In addition, the trials with incorrect responses were excluded from the final analysis (3.9%). Approximately 23.4% of trials were lost. Based on previous studies (e.g., Holcomb & Grainger, 2006; Hsu et al., 2009; Lee et al., 2004; Lee et al., 2007) and our grand average waveforms, time windows for mean amplitude analyses of the components were: 100-160 ms for P150, 180-280 ms for P200, and 300-400 ms for N400.

Repeated ANOVAs were conducted on one of radical frequency measures each time. For lateral sites, there were four factors included: one type of radical frequency (HRPF vs. LRPF or HRF vs. LRF or LRCF vs. LRCF), region (anterior vs. central vs. posterior), hemisphere (left vs. right), and electrode site (4 levels). Variables Region and Hemisphere were completely crossed yielding six regions of interest and each contained four lateral electrodes: left anterior (F3, F1, FC3, FC1), right anterior (F4, F2, FC4, FC2), left central (C3, C1, CP3, CP1), right central (C4, C2, CP4, CP2), left posterior (P3, P1, PO5, PO3), and right posterior (P4, P2, PO6, PO4). For midline sites, there were three factors included: one type of radical frequency (HRPF vs. LRPF or HRF vs. LRF or HRCF vs. LRCF), region (anterior vs. central vs. posterior), and electrode site (2 levels). Anterior region referred to Fz and FCz; central region included Cz and CPz; and posterior region contained Pz and POz. To protect against Type I error due to violations of the assumption of equal variances of differences between conditions of within-subject factors, the Greenhouse-Geisser correction was applied when evaluating effects with more than one degree of freedom in the numerator.

4.3.2 Results

Grant-average ERPs across 18 subjects were computed separately for HRPF, LRPF, HRF, LRF, HRCF and LRCF items. ERPs elicited by HRPF and LRPF conditions are displayed in Figure 6. Relative to HRPF characters, LRPF items first gave rise to a larger positivity at P150, followed by a greater P200 effect and a smaller N400 effect. Figure 7 displays ERPs evoked by HRF and LRF characters. As shown in the figure, LRF characters evoked a larger P200 effect as compared to HRF items. However, when the HRCF condition was compared to LRCF condition, no significant effects were found (see Figure 8).

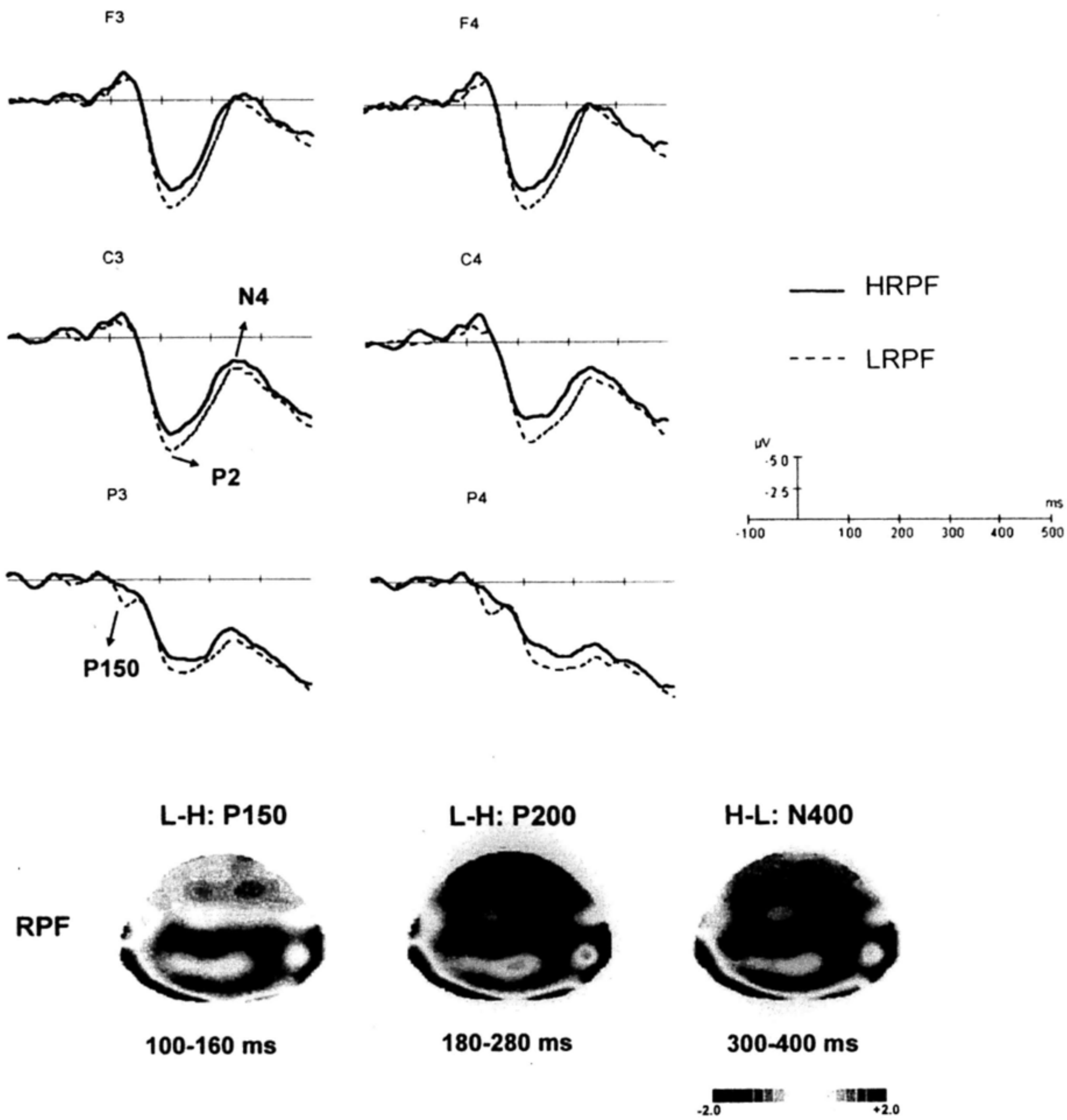

Figure 6- Experiment 3: Grand average ERP waves of the HRPF condition (solid line) and the LRPF condition (dotted line); Topographic maps (top view) of P150, P200 evoked by the LRPF condition as compared to the HRPF condition and N400 evoked by the HRPF condition relative to the LRPF condition.

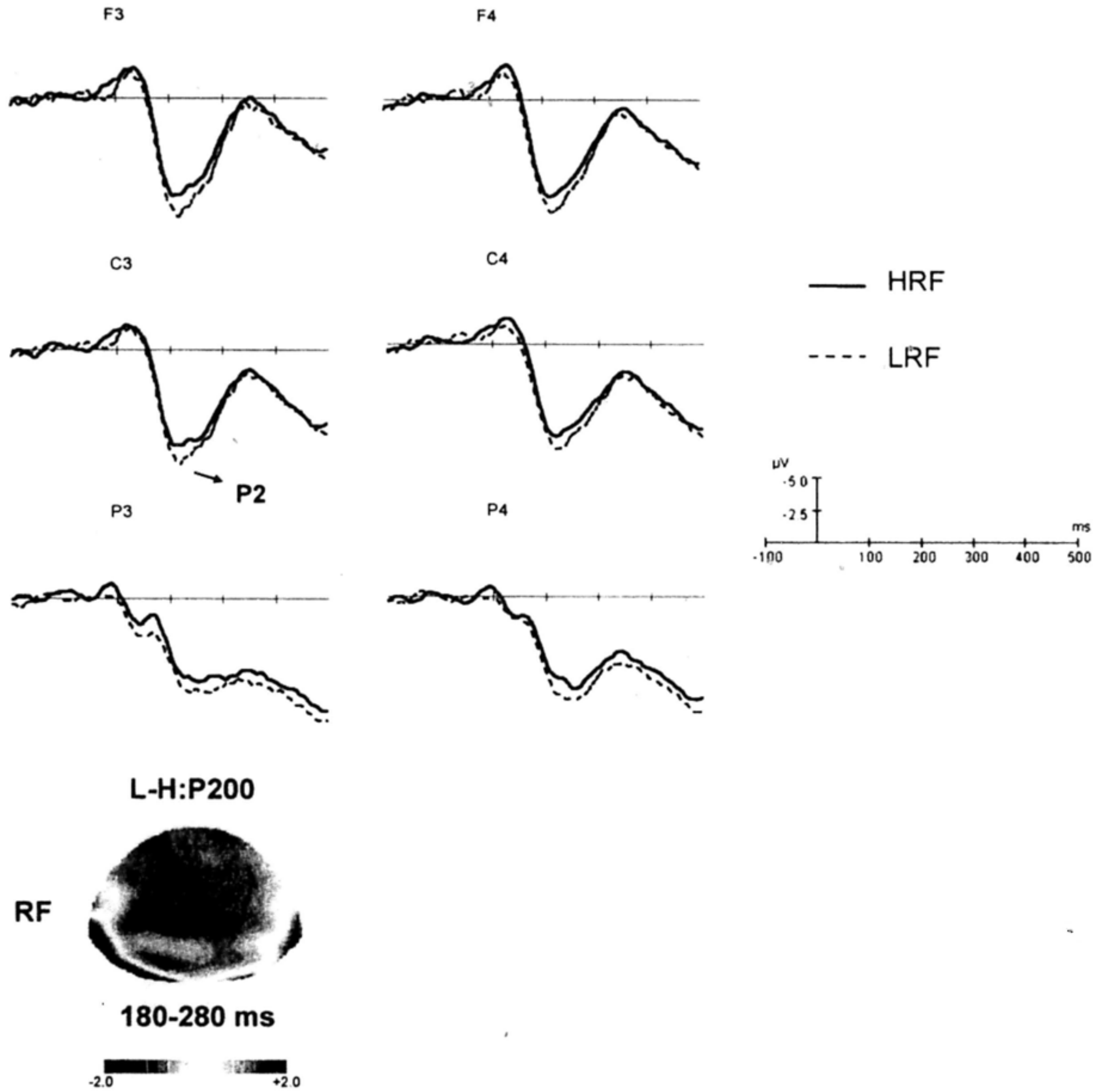

Figure 7- Experiment 3: Grand average ERP waves of the HRF condition (solid line) and the LRF condition (dotted line); Topographic map (top view) of P200 evoked by the LRF condition as compared to the HRF condition.

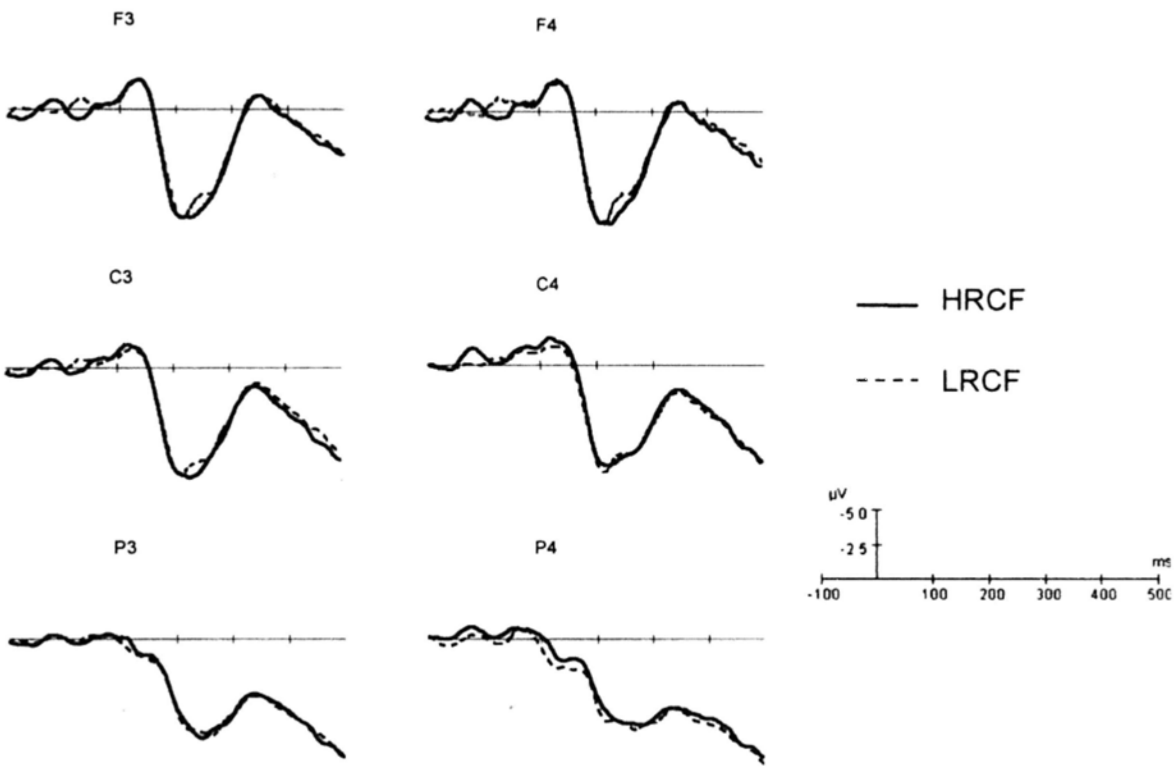

Figure 8- Experiment 3: Grand average ERP waves of the HRCF condition (solid line) and the LRCF condition (dotted line).

4.3.2.1 Effects of the RPF

Repeated ANOVA analyses revealed the significant main effect of RPF in the 100-160 ms interval, at lateral sites, $F(1, 17) = 5.84$, $MSE = 30.95$, $p < .05$, and at midline sites, $F(1, 17) = 5.58$, $MSE = 9.1$, $p < .05$. Apart from that, no other significant effects were found in either type of analyses, *ps* > .1, indicating no hemisphere and scalp distribution differences.

In addition, in the 180-280 ms interval, the main effect of RPF was also significant, at lateral sites, $F(1, 17) = 7.64$, $MSE = 52.73$, $p < .05$, and at midline sites, $F(1, 17) = 7.66$, $MSE = 14.55$, $p < .05$. Namely, the mean amplitude of P200 was significantly larger in the LRPF condition than in the HRPF condition. None of the other effects was significant, neither in lateral nor in midline analyses, *ps* > .1, indicating no hemisphere and scalp distribution differences.

Again, in the time window of 300-400 ms, the repeated ANOVA analyses showed that only the main effect of RPF was significant, at lateral sites, $F(1, 17) = 7.61$, $MSE = 34.85$, $p < .05$, and at midline sites, $F(1, 17) = 7.03$, $MSE = 11.17$, $p < .05$. Apart from this, no other significant effects were found, *ps* > .3. As shown in Figure 6, these results indicated that HRPF items evoked a greater negativity at N400 than did the LRPF items and this effect had no hemisphere and scalp distribution differences.

4.3.2.2 Effects of the RF

Repeated ANOVA analyses conducted in the 100-160 ms interval did not reveal any significant effect, *ps* > .1. Besides, although it seemed that HRF characters evoked a larger N400 compared to LRP items in the 300-400 ms time window, as shown in Figure 7, it did not reach significance in either type of analyses, *ps* > .2. However, LRF characters indeed showed a significant greater positivity at P200 relative to HRF, at lateral sites $F(1, 17) = 6.18$, $MSE = 34.92$, $p < .05$, and at midline sites, $F(1, 17) = 6.64$, $MSE = 10.2$, $p < .05$, and this P200 effect did not show any difference in hemisphere and scalp distribution, *ps* > .2.

4.3.2.3 Effects of the RCF

Repeated ANOVA analyses conducted on the RCF in each time window, including the 100-160 ms, the 180-280 ms or the 300-400 ms, did not reveal any significant effect, *ps* > .3, indicating that RCF did not exert any influence on character processing in the LDT.

4.3.3 Discussion

The present experiment explored the possible time sequence for the roles of different kinds of radical information in visual character recognition. The main findings revealed a series of ERP components, including P150, P200, and N400, associated with the RPF effect, but only P200 associated with the RF effect; no ERP component related to the RCF effect. This then suggests that the difference between RF and RPF effects has been reflected at different stages of lexical processing. In the following, we provide a tentative interpretation of different ERP components observed in this experiment.

First of all, LRPF characters elicited greater positivity at P150 than HRPF items did, whereas no difference was found between HRF and LRF items at P150. This result seems to indicate that in the initial phase of sub-lexical processing, it is the position-specific radical but not the position-free radical information that could exert influence on visual character recognition when LDT is used. To be more specific, in the present study, RF was matched well between HRPF and LRPF items. The only difference between them is the number of orthographic alternatives sharing a given radical in a specific position. The radical in the HRPF condition is related to a larger number of characters than in the LRPF condition, and thus resulted in greater activation during the early phase of orthographic representation, which then showed a smaller positivity at P150. This interpretation is congruent with prior accounts of P150. For instance, in the masked priming paradigm, relative to targets that were repetitions of primes, targets with unrelated primes usually evoked a more positive-going P150 at occipital sites (e.g., Chauncey et al., 2008; Dufau et al., 2008; Holcomb & Grainger, 2006). Researchers have interpreted this P150 effect as a component sensitive to the overall activation of sub-lexical orthographic information. That is, the more the activation of orthographic information is, the smaller the P150 will be.

Apart from P150, manipulation of RPF also modulated the change of P200 and N400. LRPF items elicited greater positive amplitude at P200 and lower negative amplitude at N400 than HRPF characters. These findings replicate prior results and support the two-stage framework for lexical access by using P200 and N400 to index the earlier and the later stages of lexical processing (e.g., Hsu et al., 2009; Lee et al., 2007). On the one hand, for HRPF items, more orthographic alternatives can be associated with a given radical, and this then will induce greater orthographic activation which causes smaller P200. On the other hand, because the characters are associated with larger orthographic neighbors sharing a selected radical in a definite position in the HRPF condition, when participants retrieve the semantic meaning of a HRPF character, more semantic competition is triggered by its neighbors. This resulted in the greater N400 evoked by HRPF items than LRPF items. A similar interpretation could be used to account for effects of RF, which showed that LRF items evoked grater positivity at P200 than did HRF items. This effect is also possibly due to the greater sub-lexical orthographic activation in the HRF condition than in the LRF condition.

In sum, the fact that both manipulations, RF and RPF, could modulate the change of P200 and only the RPF could cause changes of P150 and N400 indicates that in LDT, the effect of position-specific radicals may appear earlier (reflected by P150), and last longer (reflected by N400, as compared to that of position-free radicals in Chinese character recognition. These results are taken to mean that in the initial phase of lexical processing, visual features may be first mapped onto position-specific radical representation but not position-free radicals, as argued in Taft (2006). Besides, apart from this earlier effect, radical position might be the crucial information that overrides position-free radicals to cause semantic interference while retrieving the character meaning in a later phase. However, the findings, the earlier and stronger effects of RPF over RF's, may be due to the LDT. As shown in our behavioral results, when another task such as PDT was used, advantages of RPF effects had disappeared.

Finally, the present experiment found that the frequency of a radical when it was a simple character did not exert influence on whole-character processing. Converging with null effects of RCF in Experiment 1, these results pose a problem for proposals favoring constituent frequency effects in previous research when the same task, LDT, was used (e.g., Duñabeitia et al., 2007). One possible reason for this inconsistency may be that the words/characters in different levels of transparency have been used. In studies with constituent frequency effects, generally, transparent compound characters/words were involved. For instance, in Duñabeitia, Perea, and Carreiras (2007), only a small percentage of compound words (13 of 92) was partially opaque (at least one of the constituents was always related to the whole word meaning). In contrast, opaque compound characters were used for manipulations of RCF in the present study (20 participants, mean = 1.58 in a 1-to-5 scale, 1 = more opaque, 5 = more transparent). It has been proved by many studies that in transparent compound words, information of constituents (words) was more easily activated and then it exerted influence on the compound word processing (e.g., Marslen-Wilson, Tyler, Waksler, & Older, 1994; Sandra, 1990; Zwitserlood, 1994).

4.4 Experiment 4

4.4.1 General Method

4.4.1.1 Subjects

Thirty nine right-handed students (19 in Experiment 4a and 20 in Experiment 4b, 23 females and 16 males, aged between 19 and 27 years, with mean age of 22 years) of the Chinese University of Hong Kong participated in the experiments. All had normal or corrected-to-normal vision and were native speakers of Mandarin. None had a history of any psychiatric or neurological disorder. They were paid for their participation.

4.4.1.2 Materials

The real characters were kept the same as in previous experiments. Pseudo-characters in Experiment 1b were used as fillers in Experiment 4a, while geometric pictures in Experiment 2c were employed in Experiment 4b.

4.4.1.3 Procedure

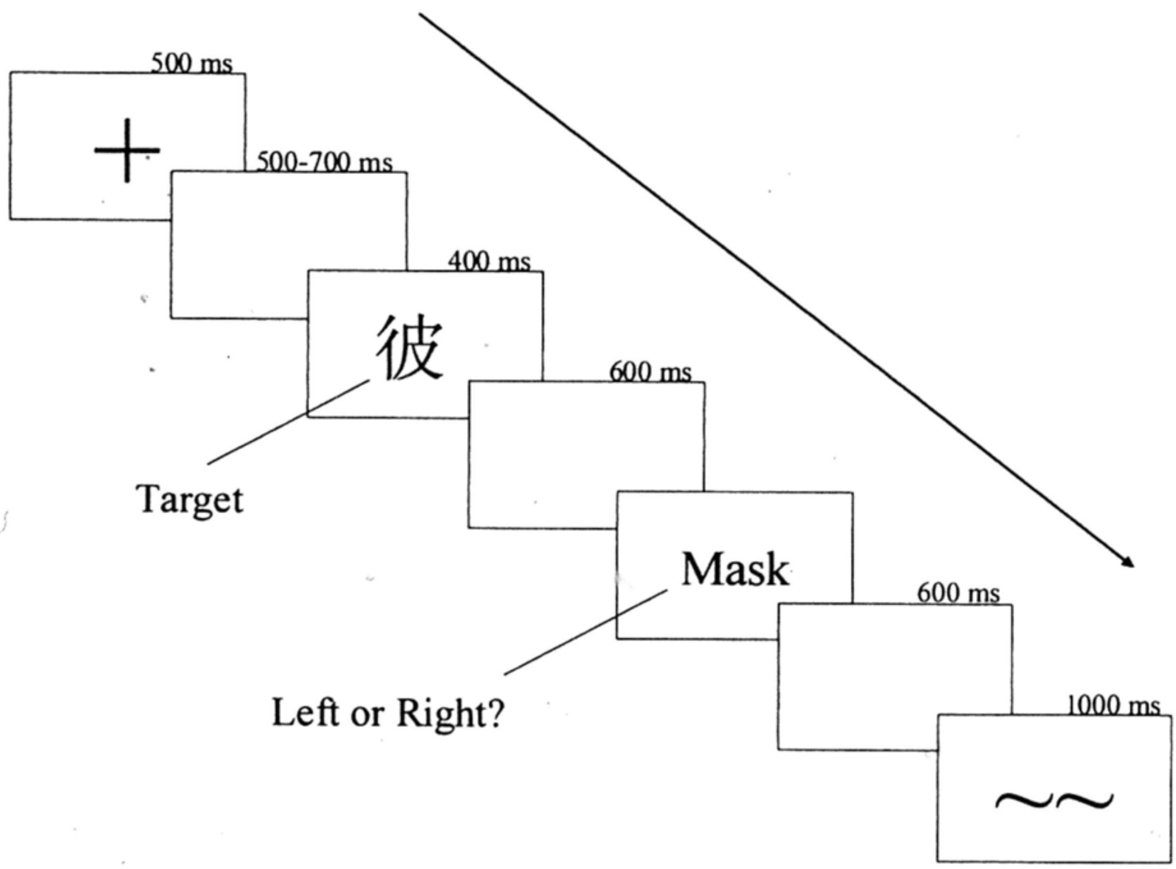

Figure 9- Procedure of Experiment 4.

At the very beginning, a cross was displayed at the center of the screen for 500 ms. After an interval of 500 ms to 700 ms, a stimulus (a character or a filler) was presented for 400 ms. It wasn't at the center of the screen, but slightly to the right or the left. After an interval of 600 ms, a mask with the size large enough to cover all positions of stimuli appeared for a maximum of 2000 ms. At this point, participants were required to judge whether the previous stimulus was on the right or on the left and respond as accurately and quickly as possible. After they pressed the corresponding key, "z" or "m", a blank was presented for 600 ms, followed by a blink signal "~~" for 1000 ms. Subjects could blink and move their eyes during this period. About 600 ms after it disappeared, the next trial began (see Figure 9). The whole experiment lasted around 2 hours. Stimuli were randomly divided into 12 blocks, each containing 58 items. Each item was randomly presented across all blocks. Again, two versions were included and stimulus positions were reversed between them.

4.4.1.4 ERP recordings and analyses

There were only two differences between ERP recordings and analyses of the present experiment and Experiment 3. First, besides the time window 180-280 ms, the mean amplitude of P200 was computed in the time window of 180-230 ms also, based on our grand average waveform. Second, more electrodes were included in the lateral site analysis. As a result, each of six interest regions contained six, not four lateral electrodes: left anterior (F5, F3, F1, FC5, FC3, FC1), right anterior (F6, F4, F2, FC6, FC4, FC2), left central (C5, C3, C1, CP5, CP3, CP1), right central (C6, C4, C2, CP6, CP4, CP2), left posterior (P5, P3, P1, PO7, PO5, PO3), and right posterior (P6, P4, P2, PO8, PO6, PO4). Totally, 13.8% of trials (error rate was smaller than 1%) for all conditions were lost due to artifact rejection and incorrect responses in Experiment 4a;

in Experiment 4b, approximately 10.8% (error rate was smaller than 1%) of trials for all conditions were lost due to the same reasons.

4.4.2 Results of Experiment 4a

ERPs elicited by the real characters in each pair of conditions are displayed in Figures 10, 11, and 12. LRPF items elicited a larger P200 with anterior-central distribution as compared to the HRPF condition (See Figure 10). HRF and HRCF conditions evoked a larger N400, respectively, relative to their own counterparts, i. e., LRF and LRCF conditions (See Figures 11 and 12). However, the N400 effect evoked by HRCF items showed a whole brain distribution, while that elicited by HRF characters was significant only at the right hemisphere (RH).

4.4.2.1 Effects of the RPF

In time window 180-230 ms, repeated ANOVA analyses revealed a significant main effect of the RPF, at lateral sites, $F(1, 18) = 5.39$, $MSE = 20.68$, $p < .05$, and at midline sites, $F(1, 18) = 4.76$, $MSE = 8.28$, $p < .05$. Significant interaction between Region and RPF was observed only at lateral sites, $F(2, 36) = 4.18$, $MSE = 6.55$, $p = .05$, and at midlines sites, $p > .2$. Further analyses revealed that in the anterior-central region, LRPF evoked a greater mean amplitude of P200 than the HRPF, anterior: $F(1, 18) = 6.6$, $MSE = 14.68$, $p < .05$; central: $F(1, 18) = 4.99$, $MSE = 8.13$, $p < .05$. There was no significant difference between HRPF and LRPF items in the posterior region, $p > .3$. Besides, in time window 300-400 ms, a significant interaction between Region and RPF was found, at lateral sites, $F(2, 36) = 5.89$, $MSE = 3.75$, $p < .05$, and at midlines sites, $F(2, 36) = 4.94$, $MSE = 0.87$, $p < .05$. However, further analyses did not reveal any significant effect in any region, *ps* > .2. Combining with the grand waveform in Figure 10, the significant interaction between Region and RPF may be due to different change pattern between HRPF and LRPF in anterior-central region from that in posterior region. In anterior-center, the amplitude of HRPF was larger than that of LRPF, whereas it was smaller than that of LRPF in posterior region. Apart from these, no other significant effects were found in either type of analyses for the remaining time windows, including 100-160 ms and 180-280 ms, *ps* > .1.

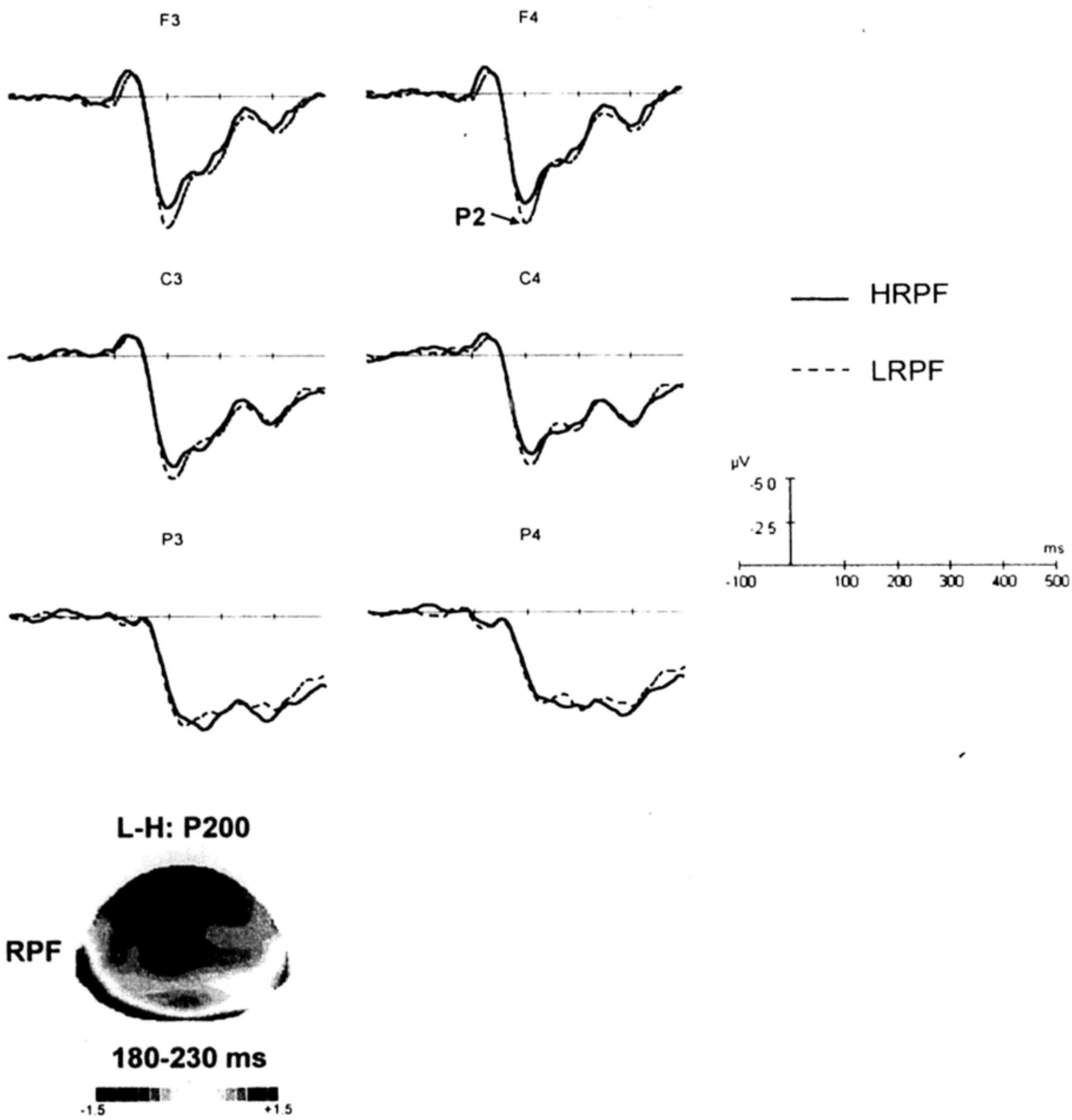

Figure 10- Experiment 4a: Grand average ERP waves of the HRPF condition (solid line) and the LRPF condition (dotted line); Topographic map (top view) of P200 evoked by the LRPF condition as compared to the HRPF condition.

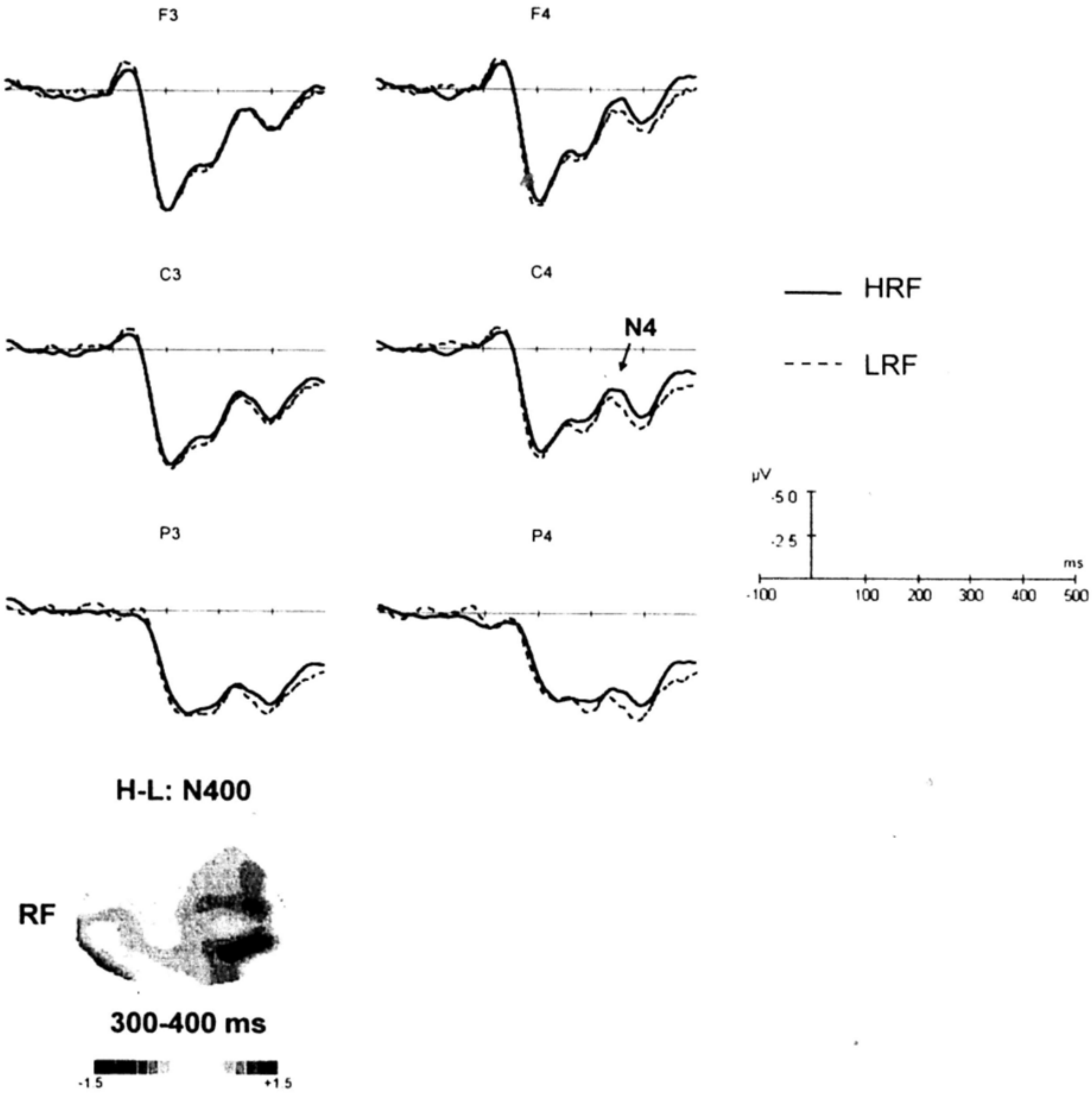

Figure 11- Experiment 4a: Grand average ERP waves of the HRF condition (solid line) and the LRF condition (dotted line); Topographic map (top view) of N400 evoked by the HRF condition as compared to the LRF condition.

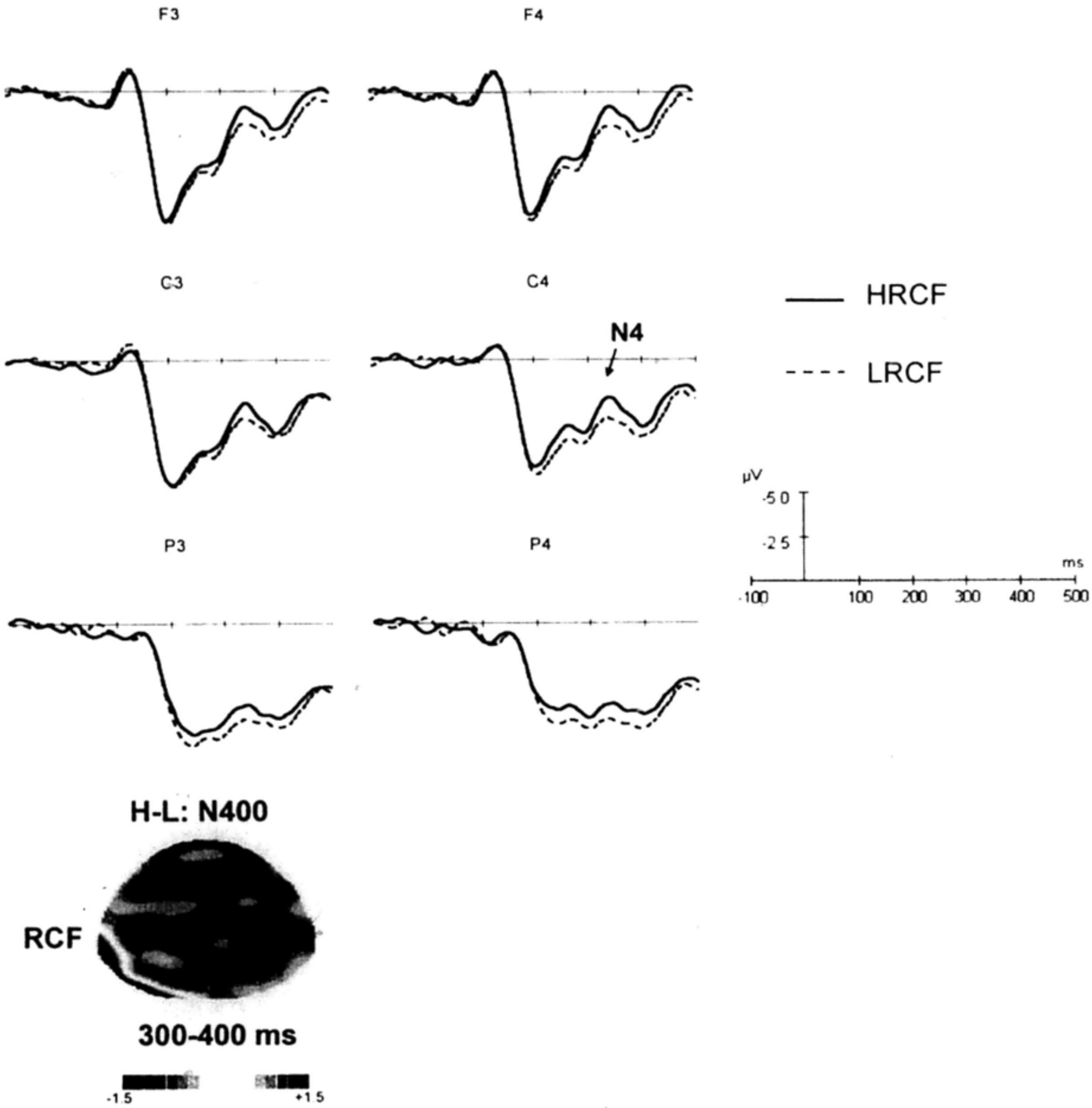

Figure 12- Experiment 4a: Grand average ERP waves of the HRCF condition (solid line) and the LRCF condition (dotted line); Topographic map (top view) of N400 evoked by the HRCF condition as compared to the LRCF condition.

4.4.2.2 Effects of the RF

Repeated ANOVA analyses conducted in time window 300-400 ms showed a significant interaction between Hemisphere and RF at lateral electrodes, F (1, 18) = 4.61, MSE = 2.46, $p < .05$. Further comparisons revealed only at the RH, mean amplitude of HRF items was significantly larger than that of LRF characters, F (1, 18) = 5.16, MSE = 11.31, $p < .05$. At the left hemisphere (LH), there was no difference between these two conditions, $p > .4$. Besides, at midline sites, no significant effects, such as the main effect of RF and the interaction between Region and RF, were found, *ps* > .3. Moreover, in time windows of P150 and P200, no significant effects were found, *ps* > .2.

4.4.2.3 Effects of the RCF

In time window 300-400 ms, repeated ANOVA analyses revealed a significant main effect of RCF, at lateral sites, F (1, 18) = 4.62, MSE = 45.73, $p < .05$; and at midline sites, F (1, 18) = 4.29, MSE = 9.73, $p = .053$, showing that HRCF items evoked a greater negativity at N400 than LRCF items. In the remaining time windows, including 100-160 ms, 180-230 ms and 180-280 ms, no significant effects were found, *ps* > .05.

4.4.3 Results of Experiment 4b

ERPs elicited by the real characters in each pair of conditions are displayed in Figures 13, 14, and 15. Generally, there was no difference between HRPF and LRPF conditions. However, relative to the LRF condition, the HRF evoked a larger N400 effect, but it was significant only at the RH. Besides, HRCF items elicited a larger negativity at N400 than LRCF characters did at the anterior region.

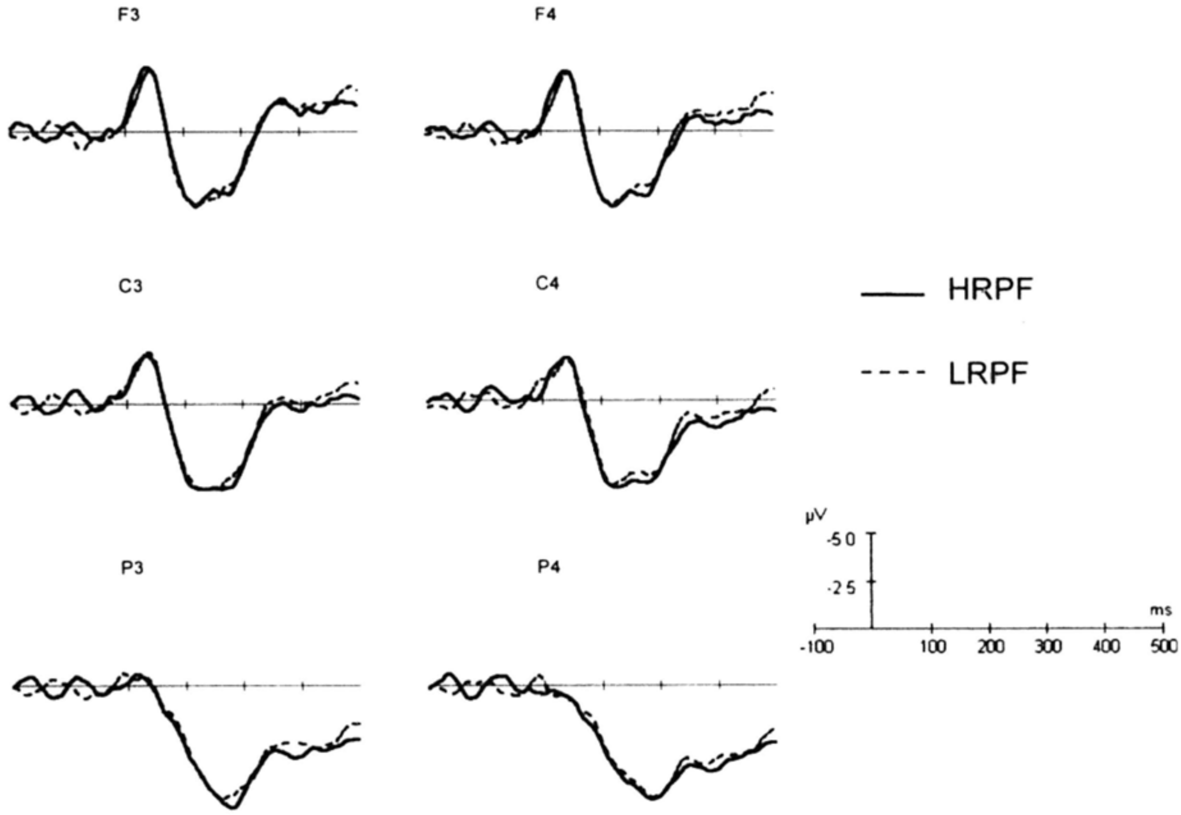

Figure 13- Experiment 4b: Grand average ERP waves of the HRPF condition (solid line) and the LRPF condition (dotted line).

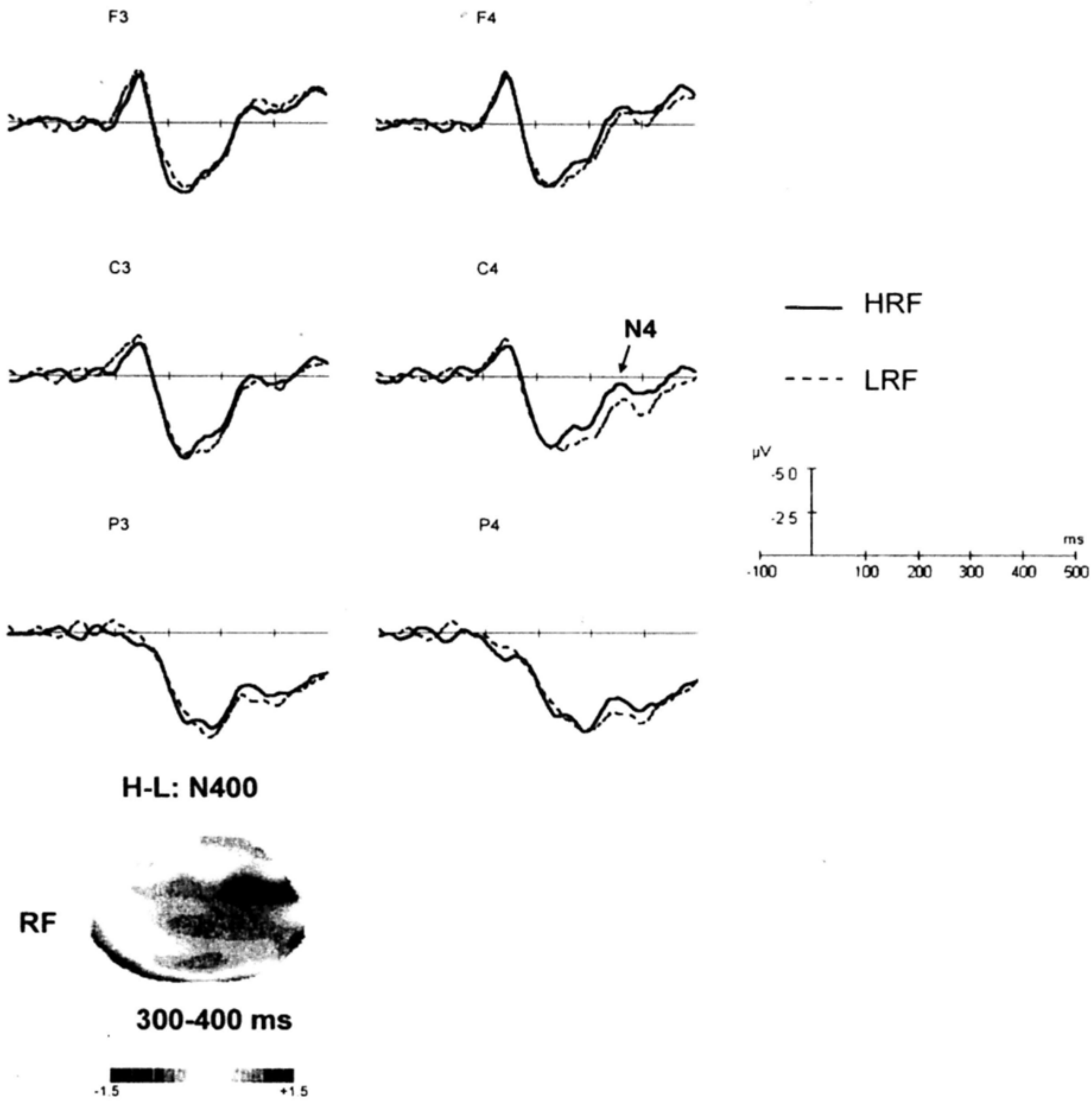

Figure 14- Experiment 4b: Grand average ERP waves of the HRF condition (solid line) and the LRF condition (dotted line); Topographic map (top view) of N400 evoked by the HRF condition as compared to the LRF condition.

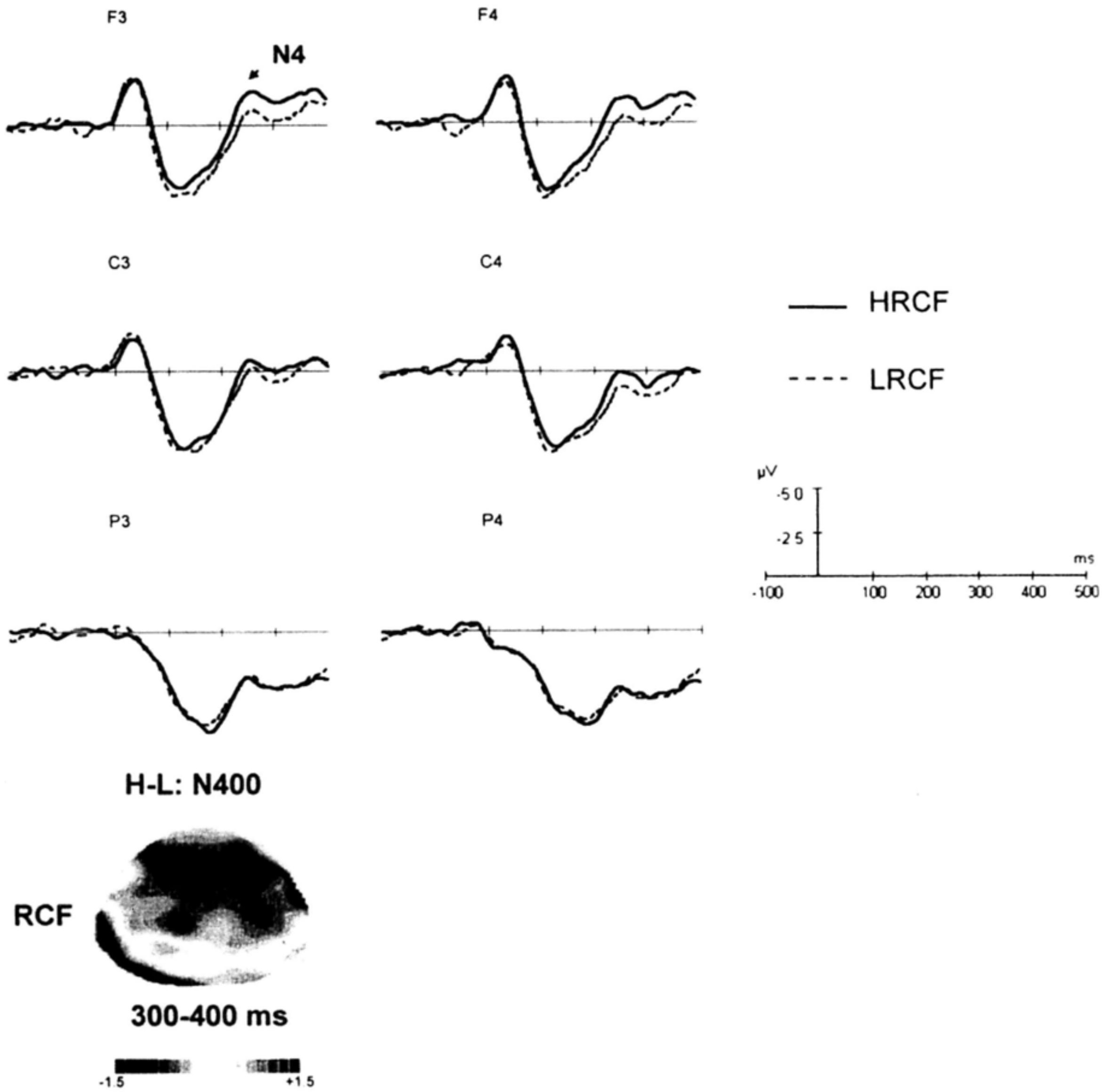

Figure 15- Experiment 4b: Grand average ERP waves of the HRCF condition (solid line) and the LRCF condition (dotted line); Topographic map (top view) of N400 evoked by the HRCF condition as compared to the LRCF condition.

4.4.3.1 Effects of the RPF

Repeated ANOVA analyses conducted on the RPF in each time window, including 100-160 ms, 180-280 ms, 180-230 ms or 300-400 ms did not reveal any significant result, *ps* > .2, indicating that there was no effect of RPF on character recognition in PDT when geometric figures were used as fillers.

4.4.3.2 Effects of the RF

In the 300-400 ms interval, there was significant interaction between Hemisphere and RF in analysis for lateral sites, $F(1, 19) = 6.26$, $MSE = 2.27$, $p < .05$. Further comparison showed a significant main effect of RF at the RH, $F(1, 19) = 5.19$, $MSE = 19.2$, $p < .05$. At the LH, no significant main effect of RF was found, $p > .1$. But, in analysis for midline sites, neither the main effect of RF nor the interaction of Region-by-RF was significant, *ps* > .05. These results showed that relative to the LRF condition, the HRF condition evoked a greater N400 and it lateralized at the RH. Moreover, repeated ANOVA analyses conducted on P150 in time window 100-160 ms and P200 in time window 180-280 ms/180-230 ms did not reveal any significant effect, *ps* > .2.

4.4.3.3 Effects of the RCF

In the 300-400 ms interval, there was a significant interaction between Region and RCF, at lateral sites, $F(2, 38) = 11.18$, $MSE = 6$, $p < .01$, and at midline sites, $F(2, 38) = 8.64$, $MSE = 1.19$, $p < .01$. Further analyses revealed the significant main effect of RCF in the anterior region, at lateral sites, $F(1, 19) = 5.71$, $MSE = 17.47$, $p < .05$, and at midline sites, $F(1, 19) = 4.97$, $MSE = 4.38$, $p < .05$. In the central-posterior regions, no significant difference between HRCF and LRCF conditions was found, *ps* > .1. Apart from these, no other significant effects were found in the remaining time windows 100-160 ms, 180-280 ms and 180-230 ms, *ps* > .05. These results indicated that the HRCF condition evoked a larger N400 effect at the anterior region than did the LRCF condition.

4.4.4 Discussion

The results of this experiment are clear-cut. In PDT, when keeping illegal characters as fillers, HRPF characters were associated with a smaller P200 as compared to LRPF characters; when using geometric pictures as fillers, this effect totally disappeared. In contrast, effects of RF were stable across different fillers in PDT, with a larger N400 to HRF than to LRF items and it lateralized at RH. Besides, ERP recordings revealed an N400 with the larger amplitude to HRCF than to LRCF characters, which distributed widely across the whole brain when pseudo-characters remained as fillers, but only frontally when including geometric figures.

Beyond the behavioral findings, Experiment 4 confirmed that both the task and the composition of materials could influence the effect of radical positions. For instance, in Experiment 4a, containing illegal characters without the demand of lexical decision was enough to trigger the position-specific radical effects. But, note that in this situation, the RPF effect became much weaker. It was only associated with the P200 with a shorter duration (i.e. 50ms), and there were no P150 and N400 any more. Under the assumption that these ERP components are related to activities of processors that assign different processing periods for visual character recognition, as revealed in Experiment 3, the results appear to demonstrate that the contrast provided by illegal characters to real ones enhances the radical position effect in the sub-lexical orthographic processing phase.

In contrast, the reliable RH N400 effects related to RF manipulation indicates that when characters are processed automatically, position-free radicals are the necessary sub-lexical orthographic information that could be retrieved in character processing. Here, the larger amplitude of N400 evoked by the HRF could be interpreted as high lexical competition when more lexical candidates are activated by the shared radical, as in Hsu et al. (2009). But why is the RH more sensitive to the RF effect rather than the LH?

According to the assumption of a new distinction between the hemispheres proposed by Chiarello (2002), words received by RH maintain and perhaps even amplify early encoding even when deeper level codes become available, whereas the LH very rapidly achieves deeper or more abstract encoding. Using this distinction, it may be that the delayed radical encoding stage in the RH during the semantic processing period enables activation of characters that share the same radicals with the target character (i.e. orthographic neighbors). This pattern of activation is not found in the LH, because characters are promoted rapidly to deeper semantic encoding stages. Actually, the right lateralization of the RF effect is in line with findings of previous studies in which the RH was proved to have primacy in representing lead neighbors of a written word (e.g., Lavidor, Hayes, Shillcock, & Ellis, 2004; Lavidor & Walsh, 2003).

In addition, with regard to the question whether inhibition effects on RTs in PDT are due to the same mechanism as facilitation effects on RTs in LDT, the answer may be no. To be specific, taking RF and RPF effects of Experiments 3 and 4 together, it seems more reasonable that facilitation effects of RF and RPF on RTs in LDT are due to the enhanced level of overall orthographic activation induced by characters with many neighbors, reflected by smaller P200 and/or smaller P150. But the inhibitory effects of RF on RTs in PDT could be attributed to the higher level of lexical competition among neighbors in the HRF (the neighborhood size is large) condition, reflected by a larger N400.

More interestingly, inconsistent with all prior experiments, Experiment 4 showed the significant effect of RCF, though the same opaque compound characters were used. These findings appear to indicate that in the automatic processing procedure, the simple character information of a radical could be activated regardless of the degree of transparency of the compound character. One concern for the results is the possible processing strategy being biased by a certain task. In LDT, because participants are required to judge whether the characters are real or not, compound characters perhaps are more likely to be processed as holistic characters and consequently, character radicals are activated as radicals. When there are no semantic associations between simple and compound characters, the difficulty to transfer the simple character information to its radical version generates the null effects of RCF on compound character processing. But when there is no such demand and actually, even no request for explicit linguistic processing in PDT, all kinds of information such as the whole compound character, the radical as a radical, or the radical as a character can be activated freely. So, in this situation, the possibilities for character radicals to be activated as simple characters are increased greatly, especially when embedded simple characters are quite familiar (with high frequency) to readers. Consequently, the ease of activation of simple characters with high frequency could influence semantic integration of whole compound characters.

Furthermore, the RCF effect was compatible with the effects of constituent frequency on compound word processing in Martínez, Duñabeitia, Laka, and Carreiras (2009), when participants were required to read sentences for comprehension. But, note that the pattern that larger N400 amplitudes were associated with HRCF but not LRCF characters is opposite to that in Martínez et al., in which high constituent frequency was found to be related to smaller amplitude of N400.

Given that the N400 amplitude is assumed to be directly proportional to the effort required by this integration process to fit each item in the representation, one concern for the different results is compound character transparency. In Martínez et al., all compound words were rated as highly transparent (20 participants). Mean transparency score was equal to 5.63 in a 1-to-7 scale (1 = more opaque, 7 = more transparent). In contrast, the present characters for manipulation of RCF are quite opaque (20 participants, mean = 1.58 in a 1-to-5 scale, 1 = more opaque, 5 = more transparent). For highly transparent words, the ease of activation of high frequency constituents speeds up integration of the compound word meaning and then this is shown as a smaller N400. For opaque characters, integration of the compound character meaning may be interfered by the ease of activation of simple characters with high frequency, and then this is shown as a larger N400. This interpretation is consistent with the viewpoints of the model proposed by Perfetti and Tan (1999), who argue that the pattern of facilitation or inhibition between compound and simple characters depends on connection parameters that reflect the consistency and validity of the radical version of simple character and compound character applying to meaning systems.

Chapter 5

General Discussion

In the present study, we have investigated whether different kinds of radical information, such as position-free radicals, position-specific radicals, and the simple character information of a radical, are available to constrain character processing across different tasks and/or compositions of materials. Furthermore, if these different kinds of radical information could influence character processing, we want to investigate the time courses for these effects?

It is found that position-specific radicals could play a role in visual character recognition, but it appears to be constrained by the task and/or the composition of materials. Results indicate that the RPF effect was quite robust in LDT across different types of illegal characters (Experiment 1). This finding is reinforced by results of Experiment 3, in which the RPF effect was associated with a set of ERP components from sub-lexical to lexical processing, including P150, P200, and N400. However, when discarding LDT but still keeping illegal characters as fillers, the effect of RPF became quite week, which existed only when ERPs were recorded and merely modulated the change of P200 (Experiment 4a). When both LDT and illegal characters have been replaced, the RPF effect disappeared (Experiment 4b).

Another central finding of this research is that different patterns were found for the effect of position-free radicals when different tasks were used. In LDT, it was the facilitation effect on RTs (Experiment 1b) and then this was shown as a smaller P200 to HRF than to LRF items in ERPs (Experiment 3). This could be interpreted as higher levels of orthographic activation triggered by the HRF than the LRF characters. In PDT, it was the inhibition effect on RTs (Experiment 2b) and then this was shown as a larger N400 to HRF than LRF items (Experiment 4), which perhaps indicates more lexical competition from neighbors in the HRF condition. In addition, it was found that only in the PDT, information of the simple character version of a radical was activated, and then it interfered the semantic retrieval of the whole-character, as shown by the change of N400 (Experiment 4).

Generally, the findings of the present study offer convergent evidence that various kinds of information represented in the radical of a character could make their own contributions to Chinese character recognition. However, the strength and the time course of their effects can be modulated by properties of experimental settings such as the task and the composition of materials. In the following section, we discuss the effects of individual radical properties on character recognition and implications of the present findings on research of Chinese character recognition.

5.1 Which is more important: position-specific or position-free radicals?

A number of previous studies have demonstrated the effects of radicals on Chinese character recognition (e.g., Taft, 2006, a review). However, in respect of the issue whether radicals exert influence with positional information or not, there is no the consistency until now. Some studies have reported that only when combined with positional information, radicals could exert influence on character recognition (e.g., Ding et al, 2004). However, the others have reported that radical positions were not the critical information that should be processed in character recognition (e.g., Tsang & Chen, 2009; Yeh & Li, 2002).

Although some researchers (Tsang & Chen, 2009) have tried to figure out the possible reasons for the inconsistent findings about the radical position effect, no direct evidence has been provided so far. Among the first set of studies which try to explore this issue, the present one suggests that the nature of task and the composition of materials may be the critical factors to cause the different effects of radical positions. It can be argued that the effects of radical positions on response latency and ERPs might be caused by LDT and illegal characters only. Once there are no such triggers, the effects of radical position would disappear. It seems that the demand of lexical decision and the composition of illegal characters biased participants to pay more attention to the radical positional information.

One may argue that there is yet another possibility for the different results of position-specific radical effects between LDT and PDT. It may be due to the different processing status of characters triggered by these two tasks. For instance, characters were recognized consciously and intentionally in the LDT, whereas they were processed under an automatic and implicit procedure in the PDT. However, we argue this is not likely to be true because of the existing findings. It has been shown that when the LDT was replaced with another explicit linguistic task, such as the illusionary conjunction or the visual search, which also required participants to process the characters consciously, still no position-specific radical effect was found in Chinese character recognition (Tsang & Chen, 2009; Yeh & Li, 2002). Hence, together with the findings of the present study, apparently, when radical positions are not particularly useful in cueing appropriate responses, Chinese readers will not weigh this information strongly during character processing, leading to the null effect of radical positions.

Although the effect of position-free radicals could also be influenced by the task and the composition of materials, the degree of influence appears to be rather weaker. For instance, only among the especially regular illegal characters such as non-characters, in which the radical positions have been emphasized heavily, i.e. when the radical positions became the only dominant cues in the LDT, the position-free radical effect disappeared (results of Experiment 1a). But, from another point of view, this may just reflect the importance of fillers in radical position effects through causing bias in participants' attention. In other situations, the effect of position-free radicals was reliable across different types of fillers. In addition, the nature of task could also influence the effects of position-free radicals, but it showed only in the time course. The LDT appears to take the effects of position-free radicals a little earlier than the PDT (comparisons between Experiments 3 and 4). This time course difference may reflect the fact that position-free radicals are processed earlier when characters are recognized explicitly and intentionally than when characters are processed implicitly and automatically. This argument is compatible with previous findings. In prior studies, researchers found that whenever there were linguistic tasks that made participants process characters explicitly, effects associated with phonetic or semantic radical combinability appeared earlier, first reflected by the change of P200 (Hsu et al, 2009; Lee et al, 2007). However, one may argue that this earlier effect of RF in the LDT may be due to the emphasis on overall orthographic processing generated by the demand of the LDT. However, this seems impossible, because it was the position-specific radicals rather than the position-free radicals that were emphasized in the LDT (e.g., Tsang & Chen, 2009).

Nevertheless, no matter what the best way is to interpret this, it is reasonable to deduce that the radical position is not the critical information that must be processed in Chinese character recognition. In fact, the strong effects of radical position found in prior studies can be attributed to the LDT and/or the illegal characters researchers employed. These findings appear to be opposite to the arguments that radicals are constrained by positions in the mental representation in Taft's model (Taft, 2006). This is because based on this argument we would predict the significant effect of radical positions even across different tasks and/or materials.

Given the radical in Chinese corresponds to the letter in alphabetic languages (Taft et al., 1999), the fact that the radical position is not important in character processing is inconsistent with the findings in alphabetic word processing, in which the relative letter positions are sure to be processed in order to recognize the word no matter what kinds of tasks or materials are involved (e.g., Grainger, 2008, a review). Such differences may be due to specific orthographic properties of radicals in Chinese characters. For instance, in English, there are only twenty-six letters among more than 118, 000 different word forms (Miller, 1995), and a letter could appear in any position in a word. Moreover, both the letter and the letter position have no specific meaning. So in English word recognition, readers could rely on only the letter form and the letter position to distinguish different words from each other. If the letter position has been ignored, it is sure that readers will be totally lost in word recognition, based on only the twenty-six letters. But, in Chinese, there are around 648 basic radicals among the 7, 000 Chinese characters (A Dictionary of Chinese Character Information, 1988) and some radicals could appear only at a particular position. For instance, radical "亻" always locates at the left position in any character that contains it. Besides, in most situations, radicals often have their own meanings. In Chinese characters, around 80% are phonetic compound characters (Honorof & Feldman, 2006). A phonetic compound character is usually composed of a semantic radical carrying some semantic information and a phonetic radical carrying some phonological information. And the more important thing is that semantic radicals often appear at the left of a character, whereas phonetic radicals often appear at the right-hand positions. Hence, in Chinese, besides radical positions, many other factors such as radical forms, radical functions, radical meanings, and even character structures also facilitate character recognition (e.g., Hsu et al, 2009; Lee et al, 2006; Tsang & Chen, 2009; Yeh & Li, 2004). Consequently, position-specific radicals become the less necessary information which must be retrieved in order to recognize the characters.

5.2 The time courses for the effects of position-free and position-specific radicals

In terms of time courses for the effects of position-specific and position-free radicals, at least one thing seems to be clear, that is, once position-specific radicals were activated, they would exert an effect earlier than position-free radicals. These findings are inconsistent with the prediction of Taft's model (Taft, 2006), which assumed position-free radicals were first activated. However, given that the radical position effect itself is not stable and it may be triggered by the LDT and the illegal characters, discussing the time sequence between position-specific and position-free radicals may be meaningless, because radical positions may not be activated at all during normal character reading when there are no triggers like illegal characters and/or the LDT.

In fact, interests in conducting neurophysiological works on the time courses of word recognition under the influence of different kinds of sub-lexical orthographic information did not emerge until recently. In these works, a set of ERP components were found along the unfolding of words (e.g., Carreiras, Perea, Vergara, & Pollatsek, 2009; Carreiras, Vergara, & Perea, 2009; Grainger, Kiyonaga, & Holcomb, 2006; Kiyonaga, Midgley, Holcomb, & Grainger, 2007), and they were treated as reflecting the processing phases from mapping visual features to sub-lexical orthographic representation and then to the whole word form or semantic selection. Yet, among the first set of studies to explore this issue in Chinese character recognition, the results obtained here have their own contributions to modeling of word processing. On the one hand, the current findings have confirmed the time sequence found in alphabetic languages, though only in the LDT, revealing that P150, P200, and N400 delegate the processing from visual features to sub-lexical orthography and then to the whole character semantic retrieval. On the other hand, beyond prior findings, especially those in English word processing, the present study has suggested that the existing models with the viewpoint of serial processing need to be revised in order to account for all findings. In particular, when characters were processed implicitly or automatically, the effects of radical information were shown in the semantic retrieval period of the whole character processing directly, and they were not first reflected in the sub-lexical orthographic processing phase (Experiment 4b).

5.3 Relationship between simple characters and compound characters

In previous research (e.g., Ding et al., 2004), it was found that the pre-exposure of the simple characters would facilitate recognition of compound characters in which the simple characters were used as radicals. Besides, some researchers also found that semantic processing of the simple characters could be facilitated if the semantic meaning of character radicals in the pre-exposure compound characters was relevant to the simple character meanings (e.g., Lee et al., 2006; Zhou & Marslon-Wilson, 1999b). In addition, the current findings demonstrate that when a radical was a simple character, its simple character frequency could also influence processing of the compound characters. And more importantly, these effects would be found more easily when characters were processed under an automatic procedure. In other words, even in opaque compound characters, a radical's simple character information could also be activated in automatic procedures.

Actually, in studies conducted on alphabetic languages, similar results have been found. That is, the constituent frequency effects were more robust during a natural procedure, silent reading (Martínez et al., 2009), than that in lexical decision experiments (Duñabeitia et al., 2007; Hyönä & Pollatsek, 1998). For instance, when both the first and the second constituent frequencies in compound words were taken into account, both effects seemed to be more noticeable during silent reading (Martínez et al., 2009), but the first constituent effects were undetected in lexical decision experiments in spite of the second constituent effects keeping the same (Duñabeitia et al., 2007).

A similar interpretation, as we discussed before, could also be used to account for findings in alphabetic languages. This may be due to the different mechanism when words/characters are processed automatically or naturally from that when they are recognized in a control procedure. In LDT, the constituents (words) are more likely to be processed as sub-lexical components. Only in transparent compound words, when there are semantic associations between the sub-lexical components and the compound words, the sub-lexical components could be retrieved. But perhaps not all constituents but the most useful ones may be activated to facilitate compound word processing. In this sense, the second constituents are activated because they were proved to be superior to the first ones in compound word processing (Hyönä & Pollatsek, 1998). In contrast, in passive word reading, all the possible information may be free to be activated due to the task naturalness and so both first and second constituents show influence on compound word reading.

To our knowledge, this study constitutes the first ERP investigation of the simple character frequency in processing of compound characters in which simple characters are used as radicals. Electrophysiological measures of Chinese character processing have allowed for capture of time courses in cognitive processing with the character unfolding that could be hardly reflected by the behavioral measures. In this study, the findings that the RCF effects were associated with N400 reveal that the interference of a radical's simple character information on compound character processing occurs at the character level, when participants integrate semantic meanings of the whole characters. This may indicate integrating difficulties in semantic meanings between simple character and compound character representations (also refer to similar interpretation in Martínez et al., 2009).

Obviously, the time point for the RCF effect, starting around 300 ms after the character onset, seems to be late as compared to the findings of Martínez et al. (2009), where lower ERP amplitudes were first elicited by words with high frequency constituents compared with those having low frequency constituents, in latency range of 100–300 ms. One possible reason for this difference may lie in the fact that almost all radicals are located at the right or the bottom in compound characters for manipulation of RCF in the present study. In Chinese, although prior research had confirmed that the impact of right radicals on visual character recognition was superior to left ones (Li, 1998; Peng, Li, & Yang, 1997; Taft & Zhu, 1997), the left or the upper one was also proved to be the first constituent that had been processed (Li, 1998; Taft & Zhu, 1997). In prior studies, characters were shown to be processed from left to right (Taft & Zhu, 1997). Hence, it is not clear whether so late effect of RCF is due to manipulations of the right or the bottom radicals of characters. Actually, in Martínez et al., both the first and the second constituents have been considered and, it was showed that the earlier ERP effects were evoked by manipulation of the first constituent frequency, not by the second constituent frequency. If the first constituent in alphabetic words could be assumed to correspond to the left radical in Chinese characters, it is quite possible that the late effect of RCF is due to manipulation of the right or the bottom radicals. In any case, the present results regarding the time course could not be simply applied to the situation when the left or the upper radicals are taken into account.

When a radical is a simple character, whether its character version shares the same representation with its radical version could not be answered by the current findings. However, it is clear that the effect exerted by position-free radical information (e.g., RF) differs from that evoked by the simple character information of the same radical (e.g., RCF) in compound character processing. For instance, first, in LDT, only the RF was found to exert significant influence on Chinese character processing. Second, in PDT, although both RF and RCF effects were associated with N400 at the same time windows, they showed different distributions, with the former lateralizing at the right hemisphere and the latter distributing over the whole brain (Experiment 4a) or anterior regions (Experiment 4b). Even with similar latency, the functional significance could be pinpointed through distinct scalp distribution pattern of N400 (Pammer et al., 2004; Spironelli & Angrilli, 2007; Weber-Fox & Neville, 2001).

Taken together, these findings have important implications for model development regarding the relationship between simple and compound characters when the former is used as a radical in the latter. On the one hand, the current study confirms that information of a radical's simple character version could be activated to exert influence in processing of even opaque compound characters. However, the precondition is to guarantee the characters are being processed under an automatic or natural condition. This demonstrates that when considering the effects of simple character information on compound character processing (e.g., Ding et al., 2004; Duñabeitia et al., 2007), the processing strategy evoked by the task should be taken into account. On the other hand, the present study provides empirical evidence that information of a radical's simple character exerts influence on compound character processing at the point when readers integrate the semantic meanings coming from simple and compound character representations together.

5.4 Activation direction between radicals and characters: Is it radical-based input?

With regard to the processes of visual character recognition, prior models either with the serial view or holding on the interactive view assume that before the whole character information is retrieved, it is the radical that is activated first (Perfetti et al., 2005; Taft, 2006). The radical-based inputs predict that manipulation of RF (those with more orthographic neighbors sharing the same radical) should first result in larger orthographic activation which can facilitate character processing at the sub-lexical orthographic level. And consequently, it should be displayed as the earlier ERP components, P200, which is known to reflect the processes before the whole character processing. Following this logic, the current finding that the RF effect was related to the N400 effect in PDT appears to question the models holding on the view of radical-based inputs. However, one may argue that in LDT or in PDT with illegal characters as fillers, we do obtain the earlier effects of RPF and/or RF, reflected by the change of P200. However, these findings do not conflict with our arguments. For one thing, these earlier effects may be due to enhancement of the position-specific radical effects triggered by the LDT or the illegal characters. For another thing, in LDT, when characters are processed explicitly (or in a control procedure), it is quite possible and normal that the time course for the effects of radical information is different from that when characters are processed implicitly (or in an automatic procedure).

Hence, with regard to the issue whether the radical could exert an early effect that is before the character-level processing, the present findings appear to show that it is associated with the whole of experimental settings. When the task could guarantee that the characters are being processed automatically (or implicitly), and there are no other factors that will enlarge the sub-lexical orthographic effects, the radicals may not be related to an early effect reflected by sub-lexical orthographic processing in Chinese character recognition. So, radicals are not necessarily the first component activated during the processing of a Chinese character. In fact, in our daily life reading, researchers indeed found that characters and not radicals were the basic units that were first activated in reading for comprehension (Chen, 1984, 1987). Moreover, given the existence of simple characters "独体字" (characters are composed of stokes directly but not radicals) in Chinese (e.g., 人 ren2, human), it is unreasonable to declare that radicals are the necessary units that must be (first) activated in Chinese character recognition. This is because if the radical-based input is true, the simple characters should not be recognized since there are no radicals in such kind of characters.

5.5 Implications for the research of Chinese character recognition: Models and Application

Several models have been proposed to explain the processes involved in Chinese character recognition. Among these models, Taft's multilevel interaction activation model (Taft, 2006) and Perfetti's interactive constituency model (Perfetti et al., 2005) are especially related to the current issue. The former could be assumed to illustrate character processing from the viewpoint of serial processing, whereas the latter is from the viewpoint of interactive processing (the detailed information has been illustrated in the section of introduction). Although these two models elaborate or predict processing of different kinds of radical information and the relationships between them, they still have difficulties in interpreting all the present findings. Given the empirical constraints in the present experiments (as well as findings in previous research), some suggestions could be given for model revision in visual character recognition in Chinese.

First, combining Taft's model (Taft, 2006) with our findings that the manipulations of radicals evoked a series of ERP components along the time course of character recognition (i.e. P150, P200, and N400), it is true that there have been three levels of presentations in Chinese orthographic system, which could be features, radicals, and characters. As in Taft's model, the feature level represents strokes and stroke connections and the character level represents character form information. But, at the radical level, radical position is not as important as assumed by researchers (e.g., Taft, 2006). Whether radicals are represented with or without positional information may depend on some kinds of experimental setups.

Second, with regard to the activation direction among different representation levels, features, radicals, and characters, it is not necessary that radicals are first activated by features and then they activate the whole characters. The issue whether the radical is activated before the character depends on many factors, such as the whole character frequency found in prior studies (e.g., Peng & Wang, 1997; She & Zhang, 1997) and the processing status of characters found here. Actually, the effects of radicals could be quite late, showing facilitation or inhibition in the semantic integration phase of character processing, especially when characters are read implicitly.

Finally, when a radical is a simple character, the influence of its character information occurs at the character level, affecting the semantic processing of the whole character. However, the pattern of facilitation or inhibition between compound and simple characters depends on connection parameters that reflect the consistency and validity of the radical version of the simple character and compound applying to meaning systems.

In any case, outcomes of these experiments have important implications not only in that they place constraints on the effects of different kinds of radical information, but also because they provide guidance for the design of experiments that should be considered. When conducting an experiment, it is necessary to take the composition of materials and task naturalness into account. The present results extend the pattern of findings in previous studies in that when exploring radical effects, interpretation of results should also be considered under the limitations of particular setups.

5.6 Limitations and directions for future studies

One of the important limitations in our research is that we are not sure whether our findings could be applied to the normal character reading in daily life. This is because, first, both LDT and PDT used in present research are not natural enough to reflect the situations in conventional reading. In LDT, illegal characters that do not appear in normal character reading are involved and, in PDT, the explicit linguistic processing of characters required in normal reading is not guaranteed. The second and also the more important one is that, as proved by our findings, effects of different kinds of information represented in radicals may be quite different when different tasks are employed. So, we are not sure whether such kinds of radical effects would keep the same once we put characters in a more natural procedure. However, note that such limitation do to not only exist in our research. Actually, prior studies also have the same problem.

Given that the ultimate purpose of studying visual word recognition is to understand how people read in daily life, the best way researchers can do is to construct tasks and materials as normally as possible. In this sense, future studies should continue investigating other ecologically valid procedure with the purpose of finally revealing radical effects in daily life reading.

Among numerous paradigms, the most direct and effective way is to put characters into sentences and then investigate radical effects in sentence reading. One of these studies was conducted by Taler and Phillips (2007), in which the neighborhood size (NS) effects were explored when participants read English sentences for comprehension. Results showed that high NS words elicited a significantly more positive-going waveform at P200 than low NS words, still exhibiting an earlier effect. Besides, Martínez et al (2009) also found the constituent frequency could influence compound word processing in Basque sentence reading. Nevertheless, there has been little research on radical processing in Chinese sentence reading. Given the big difference between alphabetic languages and Chinese, it is necessary to conduct studies in Chinese sentence reading regarding the effects of radicals.

Furthermore, only certain kinds of information represented in radicals have been manipulated in the present study. However, interactions between factors from radical and character levels should not be ignored. Actually, in previous studies, it was a common phenomenon that radical processing played a more important role in recognizing low-frequency characters (e.g., Peng & Wang, 1997; She & Zhang, 1997). Following this direction, taking character level factors into account could make our understanding more comprehensive in terms of radical effects. Moreover, issues such as the activation direction between radicals and characters could be investigated in a direct way through comparing the processing of characters and radicals.

More importantly, target radicals in the present study are those that could be used as simple characters. It is inappropriate to generalize the current findings about processing of character radicals to radicals that are not characters. For ease of material selection, character radicals have been comprehensively studied whereas little research has been conducted on recognition of non-character radicals. One existing study using non-character radicals implied that characters consisting of character radicals were recognized faster than characters containing non-character radicals (Li, 1998). This was interpreted as both radical and character levels providing stronger activation to characters than non-character radicals that were represented only at the radical level. This suggests that the effects of character radicals in recognition of Chinese characters may not be completely the same as those of non-character radicals. In order to have a comprehensive understanding about the radical effects, further studies with non-character radicals are evidently needed.

Chapter 6

Conclusion

In summary, the present study demonstrates that the relative importance between position-free and position-specific radicals in character recognition would be different in different situations. When characters are processed explicitly in the LDT, both position-free and position-specific radicals would exert influence on character recognition. But the effect of position-specific radicals is earlier and stronger than that of position-free radicals. When characters are processed implicitly in the PDT, the effect of position-specific radicals is much less stable than that of position-free radicals across different types of materials. These findings illustrate that the different results about effects of radical positions in prior studies may be due to the different tasks or types of materials being used. In addition, the present results suggest that the simple character information of a radical could play a role even in processing of opaque compound characters. But it occurs only when the whole characters are processed automatically and implicitly. We attribute this as the interfering effect and it happens when participants integrate the semantic meanings coming from the simple and compound character representations together. Lastly, the current findings question the arguments of radical-based inputs in prior theories. When considering this issue, the processing status of characters and other experimental settings such as composition of materials should be taken into account.

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Appendix A: Real Characters in Experiments 1-4

A1

Condition	Character	Radical	SN	CF	RPF	RF	RCF	Condition	Character	Radical	SN	CF	RPF	RF	RCF
HRPF	欣	欠	8	13	29	58	36	LRPF	帅	巾	5	17	1	80	32
HRPF	鸦	鸟	9	9	48	63	64	LRPF	钡	贝	9	14	4	195	46
HRPF	诅	且	7	2	16	30	293	LRPF	铋	必	10	8	3	11	272
HRPF	舰	见	10	42	18	31	871	LRPF	籽	子	9	45	4	57	861
HRPF	抄	少	7	26	15	24	978	LRPF	钎	千	8	14	7	11	998
HRPF	炸	乍	9	75	14	21	10	LRPF	伊	尹	6	67	2	10	4
HRPF	捎	肖	10	9	16	25	18	LRPF	酌	勺	10	9	9	14	19
HRPF	忘	心	7	81	74	125	576	LRPF	芳	方	7	75	3	78	566
HRPF	须	页	9	343	49	56	204	LRPF	初	刀	7	343	7	79	182
HRPF	彼	皮	8	56	15	21	216	LRPF	野	予	11	56	6	12	213
HRPF	玻	皮	9	16	15	21	216	LRPF	舒	予	12	16	6	12	213
HRPF	析	斤	8	33	25	50	404	LRPF	阵	车	6	52	2	85	435
HRPF	歼	歹	7	10	19	34	2	LRPF	幻	幺	4	5	2	41	3
HRPF	舶	舟	11	7	29	34	33	LRPF	敕	束	11	10	3	23	65
HRPF	舰	舟	10	42	29	34	33	LRPF	赖	束	13	47	3	23	65
HRPF	轨	车	6	29	43	85	436	LRPF	巧	工	5	39	5	82	394
HRPF	戒	戈	7	14	34	49	26	LRPF	钝	屯	9	11	7	11	25
HRPF	盗	皿	11	36	23	64	4	LRPF	窄	乍	10	39	2	21	10

A2

Condition	Character	Radical	SN	CF	RPF	RF	RCF	Condition	Character	Radical	SN	CF	RPF	RF	RCF
HRF	稣	禾	13	4	2	108	21	LRF	玮	韦	8	3	7	17	19
HRF	辱	寸	10	13	11	109	134	LRF	弩	弓	8	5	4	35	107
HRF	址	止	7	13	5	165	138	LRF	诛	朱	8	12	9	11	146
HRF	耻	止	10	6	5	165	138	LRF	侏	朱	8	2	9	11	146
HRF	牡	土	7	2	3	84	132	LRF	峪	谷	10	9	5	14	132
HRF	趾	止	11	13	5	165	138	LRF	忧	尤	7	17	8	14	135
HRF	扯	止	7	41	5	165	138	LRF	犹	尤	7	36	8	14	135
HRF	泪	目	8	61	3	118	188	LRF	促	足	9	64	4	11	174
HRF	旷	广	7	8	6	103	190	LRF	赎	卖	12	12	8	11	196
HRF	烛	虫	10	12	4	178	207	LRF	钒	凡	8	10	3	5	209
HRF	妆	女	6	7	3	93	276	LRF	泌	必	8	10	3	11	272
HRF	拓	石	8	15	3	114	358	LRF	蛆	且	11	5	16	30	293
HRF	肛	工	7	2	10	82	394	LRF	陨	员	9	2	4	8	393
HRF	扛	工	6	64	10	82	394	LRF	损	员	10	72	4	8	393
HRF	冯	马	5	54	8	64	462	LRF	拌	半	8	56	8	9	462
HRF	灿	山	7	3	6	130	497	LRF	泼	发	8	15	2	4	505
HRF	伯	白	7	105	10	78	517	LRF	汽	气	7	93	3	23	524
HRF	际	示	7	69	2	60	471	LRF	纹	文	7	57	5	34	461
HRF	枉	王	8	8	8	141	551	LRF	蚝	毛	10	2	4	27	549
HRF	梦	夕	11	13	9	72	17	LRF	茅	矛	8	13	1	21	13

A3

Condition	Character	Radical	SN	CF	RPF	RF	RCF	Condition	Character	Radical	SN	CF	RPF	RF	RCF
HRCF	姥	老	9	2	4	11	999	LRCF	炬	巨	8	1	8	13	48
HRCF	恍	光	9	2	5	8	543	LRCF	烁	乐	9	1	7	8	79
HRCF	驰	也	6	8	6	12	8246	LRCF	骇	亥	9	5	10	16	11
HRCF	汰	太	7	7	5	7	533	LRCF	炖	屯	8	6	7	11	25
HRCF	坟	文	7	14	5	34	461	LRCF	梓	辛	11	9	11	34	45
HRCF	胖	半	9	26	8	9	462	LRCF	纽	丑	7	29	7	10	29
HRCF	堤	是	12	46	4	8	21884	LRCF	柄	丙	9	42	2	6	121
HRCF	秘	必	10	54	3	11	272	LRCF	浪	良	10	58	9	12	58
HRCF	拨	发	8	68	2	4	505	LRCF	饲	司	8	64	5	7	99
HRCF	柿	市	9	6	2	4	570	LRCF	狐	瓜	8	9	8	15	59
HRCF	恰	合	9	20	9	25	527	LRCF	杈	叉	7	14	4	10	30
HRCF	杯	不	8	62	5	19	9652	LRCF	俗	谷	9	62	5	14	131
HRCF	季	子	7	88	15	57	861	LRCF	梦	夕	11	77	9	72	17
HRCF	埋	里	10	75	9	28	3423	LRCF	祥	羊	10	81	11	19	125
HRCF	柱	主	9	136	8	11	446	LRCF	瓶	瓦	10	127	7	13	111
HRCF	辇	车	12	1	4	85	436	LRCF	帛	巾	8	7	13	80	32
HRCF	妍	开	7	1	4	13	943	LRCF	讶	牙	6	1	6	15	57
HRCF	妩	无	7	1	4	7	1224	LRCF	胰	夷	10	2	3	6	41
HRCF	妨	方	7	5	11	78	566	LRCF	仕	士	5	7	3	84	132
HRCF	奏	天	9	109	5	27	929	LRCF	登	豆	12	94	3	25	77

Appendix B: Non-Characters in Experiments 1a and 2a

Appendix C: Pseudo-Characters in Experiments 1b, 2b, 3, and 4a

Appendix D: Geometric figures in Experiments 2c and 4b