HEMISPHERIC LATERALIZATION FOR LANGUAGE EXAMINED WITH CHINESE CHARACTERS

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The extent and nature of right cerebral hemisphere (RH) contributions to language processing remain a matter of debate. Exploiting unique features of Chinese characters, two studies investigated two questions regarding the RH's potential contributions: (1) Does the RH contribute preferentially to visual-word-form analysis of radical configurations in Chinese characters, independently of low spatial frequencies? (2) Does the RH contribute preferentially to semantic processing by accessing meaning directly through Chinese orthography, bypassing phonology? Participants were 35 right-handed native Chinese adults with at least high-school education. Participants completed both studies which incorporated divided visual field presentation of stimuli.

The first study employed a radical configuration matching task, with lateralized presentation of the second stimulus in each stimulus pair to be matched. Each pair was presented in a normal or a low spatial frequency condition. Results showed that the RH demonstrates some specialty in processing radical configurations, and that radical configuration and spatial frequency are processed as two independent entities. The frequency of exposure to different types of radical configurations was proposed as a modulator of the RH's involvement.

The second study incorporated a primed lexical decision task, with two types of primes: those conveying only semantic information and those conveying both semantic and phonological information. Target characters held weak semantic associations with both types of primes.

Lateralized stimulus presentation was used for the primes. Results suggested that the RH accesses semantic information through orthography regardless of whether phonological information is embedded.

The first study challenges the assumed relationship between the RH and radical configuration processing via the presumed connection to low spatial frequencies. The findings also lead to new questions, including whether exposure effects are potential modifiers of the RH's involvement. The second study identifies a role for the RH in accessing semantics via orthography directly. This work leads to questions about the specific neural underpinnings of this route, and about whether level of Chinese script knowledge modulates this route's accessibility. Taken together, the results of these studies and the future work they will spur will continue to advance our understanding of the RH's critical role in language processing.

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PREFACE

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1.0 INTRODUCTION

1.1. STATEMENT OF PROBLEM AND HYPOTHESES

Although it is clear that the right cerebral hemisphere (RH) contributes importantly to language processing, the extent and nature of its contributions remain a matter of debate. Most investigations have targeted broadly-defined domains such as pragmatics, theory of mind, and discourse, and/or the contributions of lexical-semantic or cognitive operations to those broad domains (Tompkins, Klepousnioptou, & Scott, 2012). Unlike the left hemisphere's (LH) relatively straightforward specialty in phonological processing for linguistically-related activities, such as speech perception and production (Brem et al., 2010; Roser, Fiser, Aslin, & Gazzaniga, 2011; Seghier & Price, 2011; see also Phonological Mapping Hypothesis by Maurer & McCandliss, 2008), the RH's specialized domains and its relationship with language-related performance are much less clear.

Crossing the language border, the RH has more involvement during visual-word-form analysis or early orthographic processing[1] when reading Chinese written script, the Chinese characters (Bolger, Perfetti, & Schneider, 2005; Tan, Laird, Li, & Fox, 2005; Wu, Ho, & Chen, 2012) than when reading English words (Dehaene & Cohen, 2011). Most studies attribute the RH's involvement when reading Chinese characters to their relatively complex visual-spatial scripts. In particular the processing of spatial configurations between radicals, which are basic

[1] The terms "visual-word-form analysis" and "orthographic processing" in some papers have been used interchangeably. This project uses visual-word-form analysis to focus on the early stage of reading process before interacting with other cognitive processes, such as phonological or semantic processes. Orthographic processing is used to suggest the potential connections/interactions with other cognitive processes during reading.

units of Chinese script (see Section 1.2 for Background on the Orthography of Chinese Script), is suggested to rely on low spatial frequencies[2] (see Section 2.1.1 for Low Spatial Frequencies and Global Contours) during the early stage of reading or the initial visual-word-form analysis (see discussion in Perfetti, Cao, & Booth, 2013). The problem with this claim is that it requires a few logical leaps.

Historically, many studies have indicated that the RH seems more efficient than the LH in processing visual-spatial information during item perception, especially the perceived item's low spatial frequency for analyzing the global contour of the item (Kosslyn et al., 1989; Marsolek, Kosslyn, & Squire, 1992; Robertson & Delis, 1986; Sergent, 1982; see Section 2.1.1 for more details). The RH's involvement is suggested to be linked to the processing of low spatial frequencies, which are assumed to compose most global contours. Then the relationship between radical configurations and low spatial frequencies is inferred because of the presumed similarities between radical configurations and global contours. In fact, evidence is controversial regarding the assumed straightforward relationship between the RH and low spatial frequency processing (Di Lollo, 1981; Fendrich & Gazzaniga, 1990; Ossowski & Behrmann, 2015; Peterzell, Harvey, & Hardyck, 1989). In addition, studies have not demonstrated a specific association between radical configurations and low spatial frequencies (Deng, Chan, & Yu, 1994; Majaj, Pelli, Kurshan, & Palomares, 2002; 郭, 1999). The first aim of this project is to disambiguate the relationship between the RH's processing preference for radical configurations within Chinese characters and low spatial frequencies. The overarching hypothesis is that the RH

[2] Items with low spatial frequencies contain fewer cycles of sinusoidal components per unit of space than those with high spatial frequencies and their contours are reflected by them. Section 2.1.1 contains more details.

is involved in recognizing the configural relationship between radicals; however, the processing of low spatial frequencies is not necessary.

The second aim of this project is to investigate a novel hypothesis regarding the RH's preferential contribution to processing Chinese characters, through a direct route from orthography to semantics. The hypothesis is inspired by the activation of bilateral neural substrates observed beyond the occipitotemporal region among adult Chinese speakers during tasks involving different linguistic processes with Chinese characters such as, spelling judgment tasks (F. Cao et al., 2010; Perfetti et al., 2013), semantic association tasks (Dong et al., 2005; Tan et al., 2000), lexical decision tasks (J. Yang, Wang, Shu, & Zevin, 2012), and item matching tasks (Jizheng Zhao et al., 2010).

Some work suggests that this bilateral activation reflects the morphosyllabic mapping principle of Chinese characters (for a review, see Perfetti et al., 2013; see Section 2.2 for details). This principle can be understood in contrast with script/segmental relationships in alphabetic languages. In alphabetic languages, words are composed of printed letters or graphemes to map onto the minimal sound units, phonemes, in spoken language. Alphabetical writing follows basically the grapheme-to-phoneme conversion rules for assembling fine-grained phonemic units (Coltheart, Curtis, Atkins, & Haller, 1993; Patterson, 1982; Tan, Laird, et al., 2005). By contrast, in Chinese script, characters are mapped onto syllable-morphemes. They convey phonological information at the mono-syllabic level and they also carry semantic information. Unlike alphabetic writing, Chinese script does not correspond to the segmental structure of speech (Leong, 1997; Mattingly, 1987). It has been suggested that Chinese readers may be able to bypass phonology and retrieve the meaning of a character directly (Liu, Perfetti, & Hart, 2003). The hypothesis related to the second aim of the current project is that this direct orthography-semantics route in reading Chinese characters is mediated by the RH. This hypothesis has not been tested systematically.

1.2 BACKGROUND ON THE ORTHOGRAPHY OF CHINESE SCRIPT

Based on the decomposed compositional structure of its visual-word forms, Chinese written language is fundamentally different from alphabetic written languages such as English on two dimensions. One is at the script level with complex visual-spatial orthographic structure, and the other at the previously introduced mapping principle level, with orthography to syllable-morpheme mapping (Perfetti et al., 2013; Perfetti, Liu, & Tan, 2005; Tan, Laird, et al., 2005). Before discussing the above two hypotheses regarding the RH's contribution in reading Chinese characters, it is worthwhile to consider some orthographic characteristics of Chinese script from which the hypotheses are developed.

The orthographic structure of Chinese written script contains a number of different levels, which are strokes, radicals or partials, characters, and words. For example, four strokes formed into a square become a character, "口, *kou3*[3],mouth" (zdic.net, 2004). This character can be used as a radical component to combine with another character, for example, "斤, *jin1*, kilogram" to form a compound character "听, *ting1*, to listen." There are approximately 560 radicals (Chinese National Language Affairs Commission, 1997). Those radicals which can sometimes function as stand-alone characters themselves are called simple characters, such as "口" and "斤." Each of these radicals has its own meaning and pronunciation. There are also radicals which can only be

[3] In the quotation marks for the characters, the italics are the Pinyin (phonetic transcripts in alphabetic codes) and numerical tonal indicator, followed by its meaning.

combined with another radical to form a compound character, such as “卩“ in “叩, *kou4,* to knock.” In contemporary usage, these radicals do not specify a particular pronunciation when they stand alone. Characters like “听” are called complex or compound characters, composed of more than one radical. Characters can then combine into words, such as “出口, *chu1 kou3,* exit” and “口角, *kou3 jue2,* quarrel.” The composition of radicals is spatially arranged into a square configuration, such as “听", “扣, *kou4*, to buckle", “所, *suo3*, place." The Chinese writing system is considered morphosyllabic because the basic meaningful writing unit, a character, corresponds to a single syllable morpheme, instead of a phoneme, in the spoken language (Ding, Peng, & Taft, 2004; Perfetti et al., 2005; Tan, Laird, et al., 2005; Jingjing Zhao et al., 2014).

2.0 BACKGROUND ON THE TWO HYPOTHESES OF THE CURRENT STUDY

2.1 RH, LOW SPATIAL FREQUENCIES, AND RADICAL CONFIGURATIONS IN VISUAL-WORD-FORM ANALYSIS

As demonstrated by the previous script examples, different from the linear layout of most alphabetic writing, except for Korean, Chinese characters are formed in a square layout of the orthographic components. Radicals of the characters are arranged with various spatial configurations, including, for example, side by side, top to bottom, or inside-outside (Perfetti et al., 2013). Such arrangement of spatial configurations has been hypothesized to give rise to the RH's recruitment in Chinese character reading, supported by results of neuroimaging evidence of bilateral (Guo & Burgund, 2010; Kao, Chen, & Chen, 2010; Liu, Dunlap, Fiez, & Perfetti, 2007; Peng et al., 2004; Tan et al., 2001; Tan, Laird, et al., 2005; X. Wang, Yang, Shu, & Zevin, 2011; Wu et al., 2012) or right-lateralized activation (Mei et al., 2015; Tan et al., 2000) in the posterior visual-processing or occipitotemporal regions. These activation patterns have been suggested to reflect the unique visual-word-form analysis processes required for the complex spatial arrangement of Chinese characters (Coney, 1998; Kao et al., 2010; Perfetti et al., 2013; Tan et al., 2001; Tan, Laird, et al., 2005). That is, the RH is specialized for analyzing the radical configurations which contain low spatial frequencies for global contours while the LH is responsible for the stroke sequences which have high spatial frequencies for local features (Kosslyn et al., 1989; Robertson & Delis, 1986; Sergent, 1982). Such a claim seems to oversimplify the RH's contribution to processing Chinese characters in terms of visual-word form analysis of the written script. As mentioned in the Introduction, the RH's involvement is hypothesized from the controversially assumed connections among low spatial frequencies, global contours, and radical configurations.

2.1.1 Low Spatial Frequencies and Global Contours

As discussed in Boreman (2001), spatial frequency in general is a property of any physical construction which is presented periodically within the perceived spatial distance. Spatial frequency is measured by how often sinusoidal components of the construction repeat or cycle per unit of distance. For the application to visual processing, spatial frequency is often operationalized as the number of contrasting luminance cycles (e.g., light and dark) over a unit of space (e.g., per degree of visual angle, referencing the spanning distance of the perceived object over the globe of the eye) (Ossowski & Behrmann, 2015; Robertson & Ivry, 2000). Items with high spatial frequencies contain more cycles per unit of space than those with low spatial frequencies. Perceptually, it is suggested that high spatial frequencies reflect fine edges of an object owing to the sharp changes, and low spatial frequencies in contrast reveal coarse changes within a larger area in a relatively homogeneous or global fashion (Hoffman, 1980; Ossowski & Behrmann, 2015).

The assumed close connection between low spatial frequencies and global forms or contours was adopted by Navon (1977) in the introduction to a series of his experiments to build up the discussion of their findings. Using hierarchical letter stimuli, in which small letters constitute a larger letter, Navon found a perceptual bias consistently manifested in the experiment series. His participants demonstrated a response bias influenced more by the object's global form than the local features. For example, compared with the response time for reporting the congruent patterns, some response times were delayed when the stimuli contained incongruous global and local patterns, such as a large letter “H” made up of small letter “t”s. Particularly, the response time interference was observed in reporting the smaller “t” but not the case when reporting the larger “H.” Later, a strong association between global contours and low spatial frequencies was exemplified in the study of Hughes, Fendrich, and Reuter-Lorenz (1990). Instead of hierarchical letters, they used stimuli with line segments and shapes to construct the local and global perceptual levels, for example, using vertical line segments to form a horizontal cluster, and small squares to form a diamond shape. In addition, they constructed a set of stimuli with contrast balanced dots which diminished the low spatial frequencies of the stimuli. The participants were asked to report the line orientation or shapes presented at the designated level (local or global) for identification. The designated global contours of these stimuli were identified faster when low spatial frequencies were preserved. When low spatial frequencies were obscured by the contrast balanced dots, the local features were identified faster.

Hughes, Kitterle, and Nozawa (1996), however, pointed out that low spatial frequencies and global contours could be two different visual constructs and that global perceptual patterns could be constructed without low spatial frequencies. An example was evident in the demonstration of Henning, Hertz, and Broadbent (1975). These investigators found when combining three sine wave gratings with high spatial frequencies into a high spatial frequency compound, the structure could be perceived as a global contour because of the periodic frequency difference. This high-frequency compound could mask or be masked by low spatial frequencies with similar contours. Nonetheless, perceptually, it seems an accepted concept that manipulating low spatial frequencies will impact more of the global forms of perceived items such as contours, while modifying high spatial frequencies will influence more the perception of local features like edges (Hoffman, 1980; Ossowski & Behrmann, 2015; Sergent, 1982).

2.1.2 The RH and Low Spatial Frequencies

In the earliest work on the relationship between the cerebral hemispheres and spatial frequencies, Sergent (1982) applied the divided visual field paradigm with hierarchical letter stimuli and added an attentional component to investigate potential hemispheric differences in the suggested levels of visual perception. The participants were asked to report if a target letter was present either at the global level formed with a larger letter contour or at the local level composed by smaller letters. Regardless of the distribution of the participants' attention prompted by the task requirements, the results suggested a RH proficiency in processing low spatial frequencies. This conclusion was evidenced by faster detection of the target at the global level (the large letter) in stimuli presented to the left visual field (LVF), and faster detection of the target at the local level (small letters embedded within the global contour) in right visual field (RVF) presentation. Sergent also proposed a few theoretical claims: (a) that such preferences occurred beyond the sensory level after two hemispheres perceived low and high spatial frequencies, (b) that the two hemispheres could both process information embedded with low and high spatial frequencies, and (c) that the hemispheric lateralization was evident when tasks required a preferred level of perceptual processing.

Sergent's (1982) proposal has been investigated in the past (Mecacci, 1993; Peyrin, Chauvin, Chokron, & Marendaz, 2003; Proverbio, Zani, & Avella, 1997) and has also received some contemporary support (Piazza & Silver, 2014; Woodhead, Wise, Sereno, & Leech, 2011). However, controversial findings in the absence of consistent supporting evidence are a fundamental concern for this proposal. For example, Peterzell, Harvey, and Hardyck (1989) applied vertical sinusoidal gratings and a divided visual field paradigm for testing hemispheric specialization in particular frequency ranges. They found no significant differences in the LVF and RVF for participants' sensitivity in detecting sine-wave gratings of different spatial frequencies in a two-alternative forced choice task. They also found no visual field-related differences in the amount of time required for detecting a blank interval between two successive identical sinusoidal gratings. Other evidence inconsistent with Sergent's proposal comes from a study with commissurotomy and healthy participants. Using a pair of Gaussian windowed sinusoidal gratings presented in the divided visual field paradigm, Fendrich and Gazzaniga (1990) asked these participants to judge the orientation of the grating stimuli as same or different and found no significant interaction between the visual fields and the spatial frequencies of the gratings. In addition, there have been studies demonstrating a relatively clearer LH/RVF advantage for high spatial frequencies with sinusoidal gratings presented in divided visual fields but showing no straightforward connection between RH/LVF and low spatial frequencies (Kitterle, Christman, & Hellige, 1990; Ossowski & Behrmann, 2015; Proverbio et al., 1997).

Ivry and Robertson (1998) argued that the above inconsistent findings resulted from the application of absolute spatial frequency bands rather than task-relevant frequency ranges. This idea was integrated into their computational model, Double Filtering by Frequencies (DFF) (Robertson & Ivry, 2000), which incorporates two layers of cross-modal filtering (visual and auditory at least) for perceived stimuli. The first layer contains an attentional monitoring mechanism to select the range of spatial frequencies relevant to the task and divide the input into two relative levels, low and high. The second layer processes the distributed input from the first layer asymmetrically in the two hemispheres, with the RH specializing in the low-pass information and LH in the high-pass information. The DFF model resonates with Sergent's (1982) hypotheses that the hemispheric differences in processing spatial frequencies emerge beyond the sensory level and that a particular range of frequencies is not processed by only one hemisphere. The model also reconciles the arbitrariness of cross-study categorization of low versus high spatial frequencies for sinusoidal gratings differing in number of cycles per degree (Robertson & Ivry, 2000).

Although the DFF model simulated hemispheric asymmetry in perception of spatial frequencies, Hsiao, Cipollini, and Cottrell (2013) identified some issues with the model. They argued that there is little neuroanatomical evidence supporting the differential modulation of frequency filtering for a discrete separation of frequency information at the proposed first layer. Neither was a differential frequency tuning mechanism found at the neuronal level in the two hemispheres, as DFF models for the second layer. Hsiao and colleagues proposed a computational model based on observed neuroanatomical differences between the hemispheres. They highlighted recent findings that the pyramidal cells in the left temporal lobe, where auditory input is processed for linguistic tasks, contain longer dendrites and contact fewer adjacent cellular columns than those do in the homologous RH region (Buxhoeveden, Switala, Litaker, Roy, & Casanova, 2001; Hutsler & Galuske, 2003). They also drew attention to a similar asymmetry in the posterior superior temporal lobe, where long-range intrinsic connections among regularly spaced neuronal clusters were revealed indicating a functional modular network (Galuske, Schlote, Bratzke, & Singer, 2000). Galuske et al. (2000) found that the diameter of those neuronal clusters was similar in the two hemispheres; however, the spacing between the clusters was about 20% larger in the LH than that in the RH.

Based on the above anatomical differences, Hsiao et al. (2013) built their computational model. They hypothesized that hemispheric asymmetries in perception of spatial frequencies result from differential neuroanatomical connection patterns at an encoding stage beyond the sensory level. They applied a Gaussian probability density function to decide the distribution of connections and held the number of connections in each hemisphere fixed. In the LH, the model had a wide probability density to simulate the long-range connections between cellular columns, and in the RH, a narrow probability density was applied to model short-ranged connections. Such modeling for the RH allows more connections among neighboring columns. Their model also simulated the hemispheric asymmetry when processing the hierarchical letter patterns that prompt the RH advantage for the targets' global level and the LH advantage for targets' local level. The narrower simulated connection distribution in the RH enabled compression of the image's pixel representations for neighboring regions of the stimuli. The compressed pixel representations from a narrower distribution were more correlated in terms of the variance in input patterns, as with global contours and most low spatial frequencies. These network characteristics reproduced the specialty for processing low spatial frequency information in the simulation. In contrast, the sparser connection distribution in the LH sampled a wider range of image's pixel representations which were more random and less correlated. This range of pixel representations contained variance in high and low spatial frequencies comparable to the fine details of the input patterns. In consequence, the LH network became comparably more proficient in preserving high spatial frequency information.

The major problem of the computational model of Hsiao and colleagues (2013) is that the proposed neuroanatomical differences are observed in the columnar and connectional structure in the region of temporal cortex involving auditory language processes. Such differences have not been found yet in the cortex related to visual processing. Nonetheless, this model provides an alternative hypothesis for the close connection between global contours and low spatial frequencies in the RH and for the inconsistent observations between the RH and low spatial frequencies.

2.1.3 RH, Global Contours (of faces), and Configurations (of Chinese characters)

Examples of the RH's involvement in processing global contours have been consistently found with hierarchical letter stimuli in different testing methods, for example, the divided visual paradigm (Sergent, 1982), and combined positron emission tomography (PET) and event-related potentials (ERP) (Heinze, Hinrichs, Scholz, Burchert, & Mangun, 1998).The association between the RH and global contours has also been inferred from studies of face recognition. For instance, consistent right-lateralized responses in the posterior visual-processing region have been observed in the N170 ERP waveform (Mercure, Dick, Halit, Kaufman, & Johnson, 2008; Rossion, Joyce, Cottrell, & Tarr, 2003) and in activation in the fusiform gyrus with functional magnetic resonance imaging (fMRI) (Grill-Spector, Knouf, & Kanwisher, 2004; Kanwisher, McDermott, & Chun, 1997). The RH's contribution to face recognition has been attributed to the analysis of the configural relations among the facial features arranged in T contour, which perceptually involves low spatial frequencies (Awasthi, Friedman, & Williams, 2011; Goffaux & Rossion, 2006). Because the spatial configurations of Chinese characters are suggested to be analogous to faces, the observed RH involvement in processing characters has been proposed to reflect a mechanism similar to that for analyzing the configural information in faces (Fu, Feng, Guo, Luo, & Parasuraman, 2012; Perfetti et al., 2013; X. Wang et al., 2011).

2.1.4 RH and Radical Configurations in Chinese Characters

In fact, different from the reliable T contour alignment of facial features, the spatial configurations between the radicals within Chinese characters are more complicated. For instance, a single radical can be positioned in different locations within a compound character. For example, when a simple character, "白, *bai2*, white" is taken as a radical, it can be found at the top of “皇, *huang2*, sovereign,” at the bottom of “皆, *jie1*, all,” to the left of “皚, *ai2*, brilliant white,” and to the right of “柏, *bo2*, cypress” (Ding et al., 2004). Moreover, the same two radicals or two simple characters can be combined into different compound characters by arranging them in different positions. For example, the two simple characters, “口” and “木, *mu4*, wood” can be combined into compound characters, such as “杏, *xing4*, apricot,” “呆, *dai1*, dull,” and “困, *kun4*, be stranded/surrounded” (Perfetti et al., 2013). 賴 and 黃 (2005) intuitively analyzed the relationships among strokes and radicals in modern Chinese characters and suggested 10 configural relationships. They further adopted the work of “Chinese character structure” from the scholars 陈 and 胡 (1994), who analyzed approximately 40000 characters in the Comprehensive Chinese character dictionary (徐, 1915), and categorized 11 different character structures. From those 11 structures, 賴 and 黃 (2005) suggested four basic spatial configurations. These are: (1) simple characters, such as “日” “月” “半”; (2) left-right/side-by-side forms, such as “明” “的” “伴”; (3) top-to-bottom forms, such as, “昱” “胃” “吉”; and (4) inside-outside/wrapped, such as “困” “周” “匡”. More complex characters can be formed by inserting a radical into the character compound. For example “鼻, *bi2*, nose” is structured with three radicals, “自” “田" "廾" vertically aligned, “懶, *lan3*, lazy" is formed with three radicals, “忄” “束" "負" horizontally aligned (Perfetti et al., 2013; 賴 & 羅, 2011; 賴 & 黃, 2005), and “森, *sen1*, forest” is three radicals shaped as a pyramid, “木, *mu4*, wood” (Ge, Wang, McCleery, & Lee, 2006).

The RH’s contribution in reading Chinese characters oftentimes has been attributed to analyzing such configural relations among radicals, which contours are assumed to contain mainly low spatial frequencies. The LH, on the other hand, purportedly contributes to analyzing the stroke sequences which assumedly contain relatively higher spatial frequencies, for example, to distinguish "凡, *fan2*, ordinary" from "风, *feng1*, wind" (Perfetti et al., 2013). Nevertheless, unlike studies on English word reading, which demonstrate a consistent, left-lateralized correlation between high spatial frequencies and English words (Majaj et al., 2002; Ossowski & Behrmann, 2015; Seghier & Price, 2011), there is a conspicuous lack of evidence regarding the relationship between Chinese characters and spatial frequencies.

The hypothetical correspondence of the radical configuration with low spatial frequency and the stroke arrangement with high spatial frequency again is derived from analogies between characters and faces. However, as already discussed, the spatial configurations between faces and Chinese characters are actually quite different. These differences in spatial configurations are evident experimentally as well, in electrophysiological findings of different N170 responses, for instance in an ERP study of the inversion effect (Fu et al., 2012). The inversion effect reflects the relative difficulty recognizing an image when it is viewed upside down compared to performance when it is upright (Diamond & Carey, 1986; Yin, 1969). Because the elements in the upright and the inverted image are the same and inversion alters only the spatial relationship among elements, the inversion effect has been suggested to represent the mechanical analysis of spatial configurations (Carey & Diamond, 1977; Kao et al., 2010; for a review, see Rossion & Gauthier, 2002). Fu et al. (2012) found the inversion effect on N170 latency was more pronounced for inverted faces than for inverted characters, suggesting their spatial configurations could be processed differently.

In terms of global configuration, as shown in Figures 1 and 2, Chinese characters are also more complicated than facial features which have only one T-shaped configuration. However, instead of 10 or 11 different configurations as 賴 and 黃 (2005) suggested, Yeh, Li, and Chen (1997, 1999) found that when classifying the shapes of Chinese characters, native readers tended to depend on the radical configurations and group them into five orthographical structures: (1) horizontal (left-right); (2) vertical (top-to-bottom); (3) P-shaped, such as “眉"; (4) L-shaped, such as "這”; and (5) Wrapped. Yeh, Li, Takeuchi, Sun, and Liu (2003) further pointed out that this grouping tendency was not found among kindergarteners or illiterate adults. It was observed, however, among both Taiwanese and Japanese undergraduates who have acquired knowledge of reading Chinese characters and Japanese Kanji, which have the same orthographic structure as characters. Nevertheless, many studies of the hemispheric contributions to Chinese character processing investigated only characters or phonograms (see Section 2.2.2 for details) with left-right spatial configuration (S. Chan et al., 2009; Guo & Burgund, 2010; Kao et al., 2010; Lin et al., 2011; L. Zhou, Peng, Zheng, Su, & Wang, 2013). Even for the investigations which included other types of characters (Hsu, Lee, & Marantz, 2011; Liu et al., 2007; Nelson, Liu, Fiez, & Perfetti, 2009; Xue, Chen, Jin, & Dong, 2006; M.-J. Yang & Cheng, 1999), the majority of the characters are left-right arranged because this arrangement is very common in Chinese characters.

On the other hand, some studies which intended to explore mechanisms specifically related to global configurations among radicals and faces adopted their character stimuli based on their own operational definition of the spatial configuration without considering the common orthographical structures. For example, Ge, Wang, McCleery, and Lee (2006) conducted a study investigating the inversion effect on faces and characters. The participants were asked to decide whether two inverted images (faces or characters) presented in sequence were the same in terms of their spatial configurations. The authors manipulated configural information by increasing the distance between local features, either the facial features in a face or the radicals in a character. Ge and colleagues found an inversion effect for faces but not for characters. That is, participants demonstrated slower responses for the inverted faces than for the upright faces, but there was no such slowing for the inverted characters. The investigators claimed that similar to faces, Chinese characters contain both featural and configural information, but unlike faces, only featural information contributes to recognizing characters. The problem is that if the spatial configuration is conceptualized in terms of the spatial relationship among the components (Kao et al., 2010), such manipulation may not actually change the global configuration among either the facial features or the radicals embedded.

Another example of assuming a similarity in configural information for faces and Chinese characters can be found in investigations of holistic processing. Holistic processing refers to the demonstration that typically, in face perception, people do not see two eyes and one nose individually but recognize the face as a whole (see discussion in Richler, Wong, & Gauthier, 2011). Chung, Leung, and Hsiao (2015) investigated the relationship between holistic processing and Chinese character processing between novice and expert Chinese readers in a divided visual field paradigm. They modified the face composite task (for a review, see Rossion, 2013) and generated their stimuli with Chinese characters. The face stimuli in the face composite task are composed of two parts, top and bottom halves. The participants are asked to judge if top halves of the two faces look the same or different. Participants in general judge two identical top halves as different when they are assembled with two different bottom halves in the face composite. Interestingly, this perceptual illusion disappears when the top and bottom halves are not spatially aligned. The interpretation of this phenomenon is that because faces are processed as a whole, the unmatched bottom halves interfere with the judgment of the top halves even when unattended. The misalignment breaks the holistic processing and releases the processing of the top halves from the interference of the bottom ones. Chung et al. (2015) asked their participants to pay attention to either the top or bottom halves of two character stimuli and to decide if they were the same. The results indicated that for expert readers, there was no RH lateralization of the performance pattern that is typically linked with holistic processing. The problem with the method is that all of the characters had the same top-to-bottom radical configuration and most of the radicals can stand alone as a simple characters themselves. These problems raise the possibility that the top or bottom halves of the characters could be processed as a whole characters independently when misaligned. In addition, the study only adopted the top-to-bottom/vertical configuration without considering other possible orthographic structures, such as the horizontal/left-right one, which is also the most prevalent configuration, nor considering the effect of misalignment on different configurations.

Without manipulating the radical configurations in experiments, it is not possible to evaluate the claim put forward in most studies (e.g., Perfetti et al., 2013) that RH involvement is due to the spatial configurations among radicals. To investigate the RH's involvement in processing the radical configurations within Chinese characters, it is necessary to utilize a task requiring analysis of the spatial configurations among radicals directly. With more than one spatial configuration among radicals, Chinese characters can play a better role than faces in exploring the RH's contribution to analyzing the global configurations among components.

2.1.5 RH, Global Contours, and Low Spatial Frequencies

The idea that global contours and low spatial frequencies could be two separate visual constructs (see Section 2.1.1) has been inferred by eliciting hemispheric preferential processing for one in the absence of the other. Volberg (2014), for example, illustrated the RH's specialization in detecting global contours without the involvement of low spatial frequencies. In a divided visual field task, he used arrays made with Gabor patches that could be either randomly arranged without a contour or contain a path contour aligned by the arrays. The participants were asked to report if a target contour was present in the stimuli. The findings revealed a LVF/RH advantage in accurately detecting a path contour. Because the contour and the non-contour stimuli consisted of the same spatial frequency spectra in the patches, Volberg argued against the conventional interpretation that the RH advantage for global contour processing results from an asymmetrical proficiency with low spatial frequency information.

According to the findings discussed to this point, the current investigation hypothesizes that the RH contributes to analyzing Chinese characters due to the radical configurations associated with the processing of various global contours, but not directly due to low spatial frequency processing. Such a phenomenon may be accounted for by the asymmetrical structure of the neuroanatomical encoding among cellular columns in the two hemispheres as embedded in the computational modeling proposed by Hsiao et al. (2013).

2.2 FROM ORTHOGRAPHY TO SEMANTICS

Beyond the view of the RH's importance for visual-word-form analysis during the initial stage of Chinese characters processing, an overlooked additional possibility is that the RH's involvement when reading Chinese characters could arise from access to semantics via orthographic processing, bypassing phonological processing. A hypothesized direct orthography-semantics access has been proposed in the Lexical Constituency Model (Perfetti et al., 2005; Perfetti & Tan, 1998). The model originally integrated the universal phonological principle, proposed by Perfetti, Zhang, and Berent (1992), claiming that reading in any language engages phonology automatically at the earliest moment with the smallest unit of the writing system. The model later specified that owing to the different interactions among phonology, orthography, and semantics in each writing system, the timing of phonological activation during reading could be different in alphabetic languages like English and ideographic languages like Chinese (Perfetti et al., 2013, 2005).

Y. Liu et al. (2003) suggested that it is possible for a Chinese reader to bypass phonology and to select a meaning directly upon processing the orthography. The morphosyllabic mapping principle in Chinese script where the writing units is mapped on individual morphemes has some implications for the hypothesized direct access to semantics via orthography. Perfetti et al. (2013) proposed the neural mechanism of this mapping was evident in the activation of bilateral superior parietal lobules (SPLs), which represent a memory component to support the process of holding the visually complicated orthographic information for further linguistic mapping (F. Cao et al., 2009, 2010).

2.2.1 RH and the Orthography-Semantics Route

The current study hypothesizes that the RH undergirds this direct semantic access in processing Chinese characters, making a contribution beyond initial visual-word-form analysis. The material below considers this hypothesis in terms of hemispheric differences in accessing semantics via orthography where the RH becomes more involved when the orthography-semantics connection requires minimal phonological processing.

The above hypothesis was first prompted by previous inconsistent results, in that some divided visual field studies suggest the RH's involvement in analyzing orthographic information from Chinese characters (Coney, 1998; Tzeng, Hung, Cotton, & Wang, 1979; M.-J. Yang & Cheng, 1999), while other studies do not (Leong, Wong, Wong, & Hiscock, 1985; Zhang & Peng, 1984). One explanation is that these inconsistent results may reflect the differential weight of phonological processing, and subsequent LH involvement, in experimental tasks (Keung & Hoosain, 1989; Zhang & Peng, 1983). For example, a right visual field (RVF) advantage, indicating initial LH processing lateralization, has been observed when experimental tasks require phonological (pronunciation judgment) processes (Leong et al., 1985; M.-J. Yang & Cheng, 1999). A RVF advantage has also been observed with tasks requiring naming of words composed of more than one character, for example "出口" instead of just "口" (Tzeng et al., 1979). Later fMRI studies provide some additional evidence in terms of hemispheric specialization in processing characters during different linguistic tasks. For example, F. Cao et al. (2010) found greater RH activation during their spelling task, when participants were asked to decide if one compound character contained the same phonetic radical embedded in the preceding compound character, than during their rhyming task. When phonological processing is particularly involved in the tasks in fMRI studies, such as those requiring rhyme or homophone judgment, there is a general pattern of LH lateralization and a LH-dominated frontal activation (Tan, Laird, et al., 2005; Wu et al., 2012).

2.2.2 Close Connection between Orthography and Phonology in English

To understand the nature of interaction among orthography, phonology, and semantics when processing Chinese characters, the interaction of those constituents in alphabetic reading may help as a contrast exemplar. The relationship between phonology and orthography in alphabetic languages, such as English, is very different from that in an ideographic language like Chinese. For instance, when reading English words, the dual-route model (Coltheart et al., 1993; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Seidenberg, 1985) suggests there are two routes to decode English orthography: an addressed route, mapping the entire word onto its sound pattern directly from representations stored in memory, and an indirect assembled grapheme-to-phoneme conversion route. English words with irregular spelling can be pronounced by retrieving their memorized phonological representations through the addressed route. For example, a word containing the letters “gh” does not assemble those letters to the sound /gh/; rather the phonology of those letters is memorized as [g], [f], or silent depending on their position in a word and their adjacent letters. English words with regular spelling can be pronounced via the addressed route when they are well-known and frequently used, or sounded out via the assembled route by converting the graphemes to phonemes. As Perfetti et al. (2013) noted, orthography has a close connection with phonology in alphabetic scripts; that is, there is fine-grained grapheme-phoneme correspondence. This relationship allows readers to regenerate a sound output from recognizing a graphic input. Simultaneously, phonological decoding boosts the acquisition of orthographic rendition, because when a phoneme string is decoded from a grapheme string, the representation of the grapheme string is also reinforced in memory (Share, 1995). Perfetti et al. (2013) suggested that word recognition in alphabetic languages can endure differences in quality of the whole word orthography due to this strong grapheme-phoneme correspondence.

The close connection between phonology and orthography in alphabetic reading is correlated with evidence of consistent left-lateralized brain activation. As suggested in a recent review (Dehaene & Cohen, 2011), the left occipitotemporal region, especially the left fusiform gyrus, shows activation in response to the mapping process between visual-word forms/graphemes and speech sounds/phonemes during alphabetic word reading. Such activation is explained by the phonological mapping hypothesis (Maurer & McCandliss, 2008) and also suggested to be automatic by the universal phonological principle (Perfetti et al., 1992). In alphabetic languages, it is questionable whether a word's meaning can be retrieved without phonological processing in decoding.

2.2.3 Non-straightforward Phonological Decoding in Chinese

The relationship between phonology and orthography in Chinese writing is a very different story. First of all, it is a mistake to assume that the potential access to semantics via orthography solely results from the ideographic or logographic characteristic of Chinese characters. The ideographic characteristic was derived from some ideographs inheriting the pictorial visual-word-form dating back more than 3000 years. However, less than 20% of Chinese characters nowadays are ideographs which maintain the obvious pictorial forms (DeFrancis, 1989; Jingjing Zhao et al., 2014). The vast majority of modern Chinese characters are actually “phonograms” (80 – 90%), which are compound characters consisting of a semantic radical, usually on the left, and a phonetic radical, usually on the right (Hsu et al., 2011; Tan, Laird, et al., 2005; Jingjing Zhao et al., 2014). “听" and "扣" are both the examples of phonograms.

Due to their disproportionate representation among characters, phonograms are usually used to demonstrate the typical processing of Chinese characters in tasks such as deciphering orthography and obtaining the embedded phonological and semantic information. As the decomposition of “听," demonstrated in Section 1.2, “扣, *kou4*, to buckle” contains a semantic radical on its left “扌,” which is an unpronounceable radical derived from the simple character “手, *shou3*, hand,” and a phonetic radical on its right “口, *kou3*". It is noteworthy that a simple character can function as either a phonetic or a semantic radical in different compound characters. With such a composition of semantic-phonetic compounds, usually the meaning of a phonogram is indicated by its semantic radical and the pronunciation is suggested by its phonetic radical. However, only about 28% of phonetic radicals sound the same as their resultant compound characters and fewer than 40% of phonetic radicals sound approximately like the compound characters. Most phonetic radicals give only a clue to the phonograms without the tonal patterns, sometimes only the consonant onset or the vowel ending (DeFrancis, 1989; Tan, Laird, et al., 2005; Tzeng et al., 1979; Jingjing Zhao et al., 2014).

A *regular* phonogram is one whose phonetic radical provides the same pronunciation, regardless of tonal difference. For example “植, *zhi2*, to plant” is a regular phonogram with a semantic radical “木” and a phonetic radical “直, *zhi2*, vertical/straight.” An irregular phonogram is one whose phonetic radical does not provide a close pronunciation clue. For example, “贻, *yi2*, present” has a semantic radical “贝, *bei4*, shell/symbol of money” and a much less consistent phonetic radical “台, *tai2*, platform” (Lee, Tsai, Su, Tzeng, & Hung, 2005; L.

Zhou et al., 2013). Again, even the script-to-sound mapping among regular phonograms is far from consistent. This is because many phonetic radicals only provide approximate phonological cues to the entire character, such as onset or rhyme of the syllable, and tonal indication is inconsistent. There are also phonograms whose semantic radicals do not provide clear semantic associations with the resultant compounds, which are known as semantically opaque phonograms, but such cases are not very common. For example, the character "弥, *mi2*," meaning "full" contains the semantic radical "弓, *gong1*," meaning "bow", and the phonetic radical "尔" indicating the rhyme "*i*" (M.-J. Cheng & Weekes, 2004; L. Zhou et al., 2013).

In general, the function of semantic radicals is more reliable than that of phonetic radicals (Ho, Chan, Lee, Tsang, & Luan, 2004). Williams and Beaver (2010) demonstrated the bias of relying on information from semantic radicals more than phonetic ones in a lexical decision task. They found that the characters containing opaque semantic radicals induced higher error rates and a trend toward longer response times than the characters containing irregular phonetic radicals. In addition, from a corpus analysis of characters in school textbooks, Shu et al. (2003) found that more than 85% of the phonograms contain the semantic radicals that provide meaning associated with the whole compound characters. Jingjing Zhao et al. (2014) suggested that because of the ambiguity in script-to-sound mapping among Chinese characters, the computation from orthography to phonology is much less efficient than it is in alphabetic languages, and the computation from orthography to semantics may be more efficient due to the more reliable script-to-meaning mapping. Such computation is suggested to contribute more to naming words composed of Chinese characters than to naming alphabetic words.

As discussed previously, less than two-thirds of phonograms comprise phonetic radicals providing some clues to the pronunciation of the whole characters, and non-phonograms or irregular phonograms do not have this phonological scaffolding in their components. These diverse irregularities in mapping orthography to phonology among Chinese characters have led to the suggestion that reading Chinese characters requires mainly the addressed route to look up phonological representations via orthographic forms directly (Lu, Tang, Zhou, & Yu, 2011; Seidenberg, 1985; Tan, Hoosain, & Peng, 1995; Jingjing Zhao et al., 2014). In fact, however, spoken Chinese is highly homophonic and various orthographic forms sound the same. Depending on memorized phonological units solely is not sufficient to access designated meanings (Tan, Spinks, Eden, Perfetti, & Siok, 2005). When such a tremendous number of written forms can be mapped onto one spoken sound, the addressed route seems inadequate. More complex deciphering of the compositional structure of the orthographic forms at their sublexical or radical level seems inevitable (Perfetti et al., 2013), which cannot be accommodated by either the addressed or the assembled routes proposed for alphabetic word reading.

2.2.4 Deciphering Chinese Characters

Perfetti et al. (2013) suggested that the deciphering process for reading Chinese characters is dependent on a mechanism of whole character memory and component/radical-mediated heuristics assisted by both phonetic and semantic radicals.

By examining the educational curriculum for character reading in the Chinese school system, it is possible to learn how Chinese readers acquire the skills to cope with the complicated relationships among orthography, phonology, and semantics. Chen and Yeh (2009), integrating findings from Shu et al. (2003), pointed out that during the first and second years at elementary school, students learn the simple characters, mostly to pave their way to learn compound characters. During later grades, when students learn compound characters (which are usually phonograms), they may apply the phonological and semantic knowledge of those radicals to sound out the whole character. The skill is useful for regular phonograms only. Therefore, when the students realize that some phonetic radicals only hint at the approximate sounds of the whole characters, they learn how to use the statistical combinability of those particular radicals. This process is acquired when the radicals are shared with other radicals composing different compound/whole characters and is applied to determine the weighted consistency of the sounds. This heuristic skill has been called the orthography-phonology correspondence rule (Tzeng, Lin, Hung, & Lee, 1995). Eventually, students learn that there is not an absolute connection to the sound or the meaning from the radicals, but the radicals still offer some degree of phonological and semantic information. Chen and Yeh (2009) also pointed out when advancing through the curriculum, there are more low-frequency phonograms to be acquired in the textbooks (Shu et al., 2003). For phonograms, the lower the frequency, the more transparent and regular are their embedded semantic and phonetic radicals. Students then can apply their accumulated radical knowledge of the semantic and phonological information to decipher the low-frequency characters (Chen & Yeh, 2009; Perfetti et al., 1992; Shu et al., 2003)(Perfetti et al., 1992; Shu et al., 2003; 陳 & 葉, 2009). In addition, Shu et al. (2003) found that the high-frequency characters taught in earlier grades are usually less visually complex than the low-frequency characters learned in later grades.

Inspired by the models of reading acquisition in alphabetic languages (Frith, 1985; Gough, Juel, & Griffith, 1992) and integrating the results from their own studies (Ho, Chan, Tsang, & Lee, 2002; Ho, Yau, & Au, 2003), Ho et al. (2003) proposed an acquisition model to describe Chinese character learning in three stages. The first is called the logographic stage when students take each Chinese character as a logograph and learn the association between the visual features and the sound. The second is the cipher stage when students learn about the orthographic structures which provide the positional and functional regularities of radicals, such as the semantic and phonetic radicals in phonograms. Ho and colleagues (2004) suggested that at this stage, students discover the strategies to decipher new characters and save some memory resources by not memorizing each character individually. The last stage is called the orthographic stage when students learn to process the character components or radicals and the whole characters as units for efficient and automatic character processing. Evidence consistent with these levels of orthographic structure has been reported by 洪, 李, 陳, & 周 (2010). They found differences between children and adults in processing whole characters, such that children relied more on the semantic transparency of radicals when judging the semantic association of two compound characters presented visually and auditorily in sequence. Adults were suggested to be more proficient in accessing the meaning of the whole compound without much interference from the radical components. Additionally, based on the acquisition hierarchy in character reading from Ho et al. (2003), one could infer the possibility that before reaching the orthographic stage, the meaning of "雷, *lei2*, thunder" can be accessed with the skills acquired in the cipher stage by deciphering the orthographical structure of the radicals on the top, "雨, *yu3*, rain" and the bottom, "田, *tien2*, farm field" with little scaffolding from retrieval of the phonological information. One other demonstration is the connection to the meaning of "鳴, *ming2*, cry of birds" by configuring the two radicals "口, *kou3*, mouth" and "鳥, *niao3*, bird."

2.2.5 The Importance of Orthography in Chinese Reading

Different from English, which is not equipped with complicated visual-word forms and unique morphosyllabic mapping, orthographic knowledge in Chinese refers to understanding the positional constraints within characters such as radical configurations, and the functions of the intra-character components such as semantic and phonetic radicals and their integration (Leong, Loh, Ki, & Tse, 2011). Functionally, orthography plays a crucial role in processing Chinese characters to access meaning, due to the rampant homophones in written Chinese which further complicate the already intricate phonology-semantics connection (Tan, Spinks, et al., 2005).

In order to master orthographic processing and its complex visual scripts, a prevalent learning strategy in elementary schools is for students to practice writing individual characters by repeatedly copying them (D. W. Chan, Ho, Tsang, Lee, & Chung, 2006; Tan, Spinks, et al., 2005). Not surprisingly, then, studies have shown a close relationship between Chinese readers' writing skill and reading ability. For example, in a cross-sectional behavioral study, Tan, Spinks, et al. (2005) found Chinese children's character reading ability is more strongly related to their writing skills, measured by copying characters and pseudo-characters in a limited time period, than to their phonological awareness, measured by tasks such as onset/rhyme judgment. A similar implication arises from a study with adult learners of Chinese, showing that behavioral training on writing characters improved processing in lexical decision and character meaning decision tasks, but training on typing the alphabetic coding of those characters (Pinyin) only facilitated the character-pronunciation association (Guan, Liu, Chan, Ye, & Perfetti, 2011).

In addition to strategies learned at school, the dependence on orthography also impacts Chinese readers' behaviors when learning other languages. In a study with English as a Second Language (ESL) learners, Wang, Koda, and Perfetti (2003) found that in a semantic category judgement task Chinese ESL learners made more mistakes than Korean ESL learners to stimuli which were more similar in spelling to the category exemplars than those less similar in spelling. Moreover, different error patterns were observed in a phoneme deletion task, in which one needed to delete the designated phoneme in an English word and then spell out the new word after the deletion. Chinese ESL learners performed more poorly than Korean ESL learners and also made more mistakes that were incorrect in phonology but acceptable in orthography.

On the other hand, studies with English speakers who are learning Chinese suggest a correlation between the development of orthographic representation and the activation of bilateral or right-lateralized occipito-temporal regions when reading Chinese script, as opposed to left-lateralized activation with English (Nelson et al., 2009; Perfetti et al., 2007). The increased RH involvement in reading Chinese has been interpreted as an accommodation representation for the demanding analysis of the orthography of Chinese characters (Perfetti et al., 2013).

To this point, it has been argued that Chinese orthography plays a crucial role in processing characters. Because of the complicated visual-spatial components of Chinese orthography, studies have demonstrated the RH’s involvement for processing its spatial structure (e.g., Bolger et al., 2005; see discussion in Perfetti et al., 2013). This proposed study aims to further the explanation of the RH’s involvement to a stage beyond visual-word-form analysis, the level of semantic access, using stimuli that decompose orthographic structure and require little phonological decoding.

2.2.6 Orthography-to-Semantics Route in Processing Chinese Characters

The hypothesized orthography-semantics route has been based on several studies. The following demonstrate the possibility that the semantic representation embedded in the orthographic structures, both the radicals and the whole characters, can be accessed automatically regardless of the positional functions assigned within phonograms. In a primed naming study, when a target simple character, such as "雨, *yu3*, rain," was semantically related to a phonetic radical, such as "風, *feng1*, wind" embedded in the prime, "楓 , *feng1*, maple," facilitation was found even though "雨" is not semantically related to the whole character "楓" (X. Zhou & Marslen-Wilson, 1999). Also, such facilitation was found when the target was a relatively inconsistent phonogram. For example, "紫, *zi3*, purple", which contains a phonetic radical "此, *ci3*, this" and a semantic radical "糸, *no consistent pronunciation*, silk," was primed by an inconsistent phonetic radical, "青, *qing1*, blue" embedded in the irregular prime, "猜, *cai1*, guess." The representation of these orthographic units, including the whole characters, the semantic radicals, and the phonetic radicals, were suggested to be activated in parallel during word identification from the priming effect crossing the assigned positional functions within a phonogram. One possible indication is that these orthographic representations may have direct access to the phonological and semantic representations. A similar pointer to this direct route was exemplified in an ERP study by Lee, Tsai, Huang, Hung, & Tzeng (2006). They found semantic facilitation from the same stimuli used by Zhou and Marslen-Wilson (1999), indicated by reduced N400, when "雨, *yu3*, rain" was primed by "楓, *feng1*, maple." The reduced N400 was also elicited when "買, *mai3*, buy" was primed by an irregular phonogram "讀, *du2*, read," where an embedded inconsistent phonetic radical, "賣, *mai4*, sell," was semantically related to the target.

In another study, Hsu and colleagues (2011) suggested the results from Lee et al. (2006) as evidence for automatic sublexical semantic activation of Chinese phonetic radicals during the early stage of visual word recognition. Moreover, other than the parallel activation via the phonetic radicals, supporting evidence of a direct route to meaning for the semantic radicals was also found by the priming study of L. Zhou et al (2013). They found a semantic priming effect from low-frequency semantically opaque phonograms, for targets that were semantically related to the semantic radicals in the primes, but not to the primes themselves, nor to high-frequency primes. For example, the target "箭, *jian4*, arrow" was primed by the semantic radical, "弓, *gong1*, bow," embedded in "弥, *mi2*, full."

In the Lexical Constituency Model (Liu et al., 2003; Perfetti et al., 2005) a possible route was suggested to connect the orthographic representation through the characters to the meaning, or the semantic representation. The model modified the original idea of the role of phonology as expressed in the universal phonological principle. It specified that even though phonology activation is universal across languages, the time course of the activation between phonology and semantics after orthographic processing could vary depending on the properties of the script of the language. Taking Chinese characters as an example those properties could be things like lexical frequency, phonological consistency of radicals, number of homophones, and meaning. The modified model linked the onset of phonology to an orthographic threshold during character identification. Specifically, it suggested that at the point of matching written input with the orthographic representation, when this threshold is reached, it activates the pronunciation and the meaning of the character in parallel. When one radical does not stand alone as a simple character itself and therefore does not have specific pronunciation or phonological representation but only an orthographic representation, it can be only connected to the semantic representation (Perfetti

& Tan, 1999). Such direct orthography-semantic connection can be demonstrated by the example, "忄" derived from the simple character "心, *shin1*, heart," which retains the meaning related to heart but cannot be pronounced. It can be combined into a compound character, such as "怀, *huai2*, embrace," with an irregular phonetic radical, "不, *bu4*, no." Similarly, the character "扎, *za1*, to prick" contains another non-stand-alone semantic radical "扌" derived from the simple character "手, *shou3*, hand," and a radical "乚", which has no consistent pronunciation or contemporary meaning.

2.2.7 The RH and the Orthography-to-Semantics Route

Even though the orthography-semantics route has been suggested during the processing of Chinese characters, the hemispheric foundations for this route have not been discussed in depth. Some fMRI studies demonstrate a possible RH contribution in parietal and frontal areas through different experimental tasks involving minimal phonological processing. For example, RH lateralized activation has been revealed, compared with fixation, when passively viewing both simple characters with precise meaning associations and phonograms, which consist of semantic radicals (Tan et al., 2000). RH lateralized activation is also evident when viewing upright and inverted characters compared to other objects with the same orientation (Jizheng Zhao et al., 2010). In a semantic association judgment task for two characters, Dong et al. (2005) found RH lateralization during a semantic association task compared with the activation during a consonant matching task. Right-lateralized activation has even been observed when deciding the lexicality of pseudo-characters, made up of two sequentially legal radicals that are never actually combined in the language (J. Yang et al., 2012). Because the activation in the above studies occurred beyond the posterior visual processing regions, the representations yielded by orthographic processing may connect to their semantic representations.

It has been suggested that the involvement of the parietal region in such studies results from the demands of spatial working memory (D'Esposito et al., 1998; Perfetti et al., 2013; E. E. Smith et al., 1995; Tan et al., 2000). Due to the visually complex orthographic configurations of Chinese characters, the orthographic information may need to be sustained before the recognition threshold is reached (Perfetti et al., 2013). For many characters like phonograms, this process may represent the connection stage while deciphering the sublexical or radical information from the orthography to map to the arbitrarily linked semantic and phonological representations.

The involvement of the right frontal region in Chinese character processing when phonology is minimized may represent some degree of semantic processing in meaning activation through orthographic deciphering. Right-lateralized semantic processing directly after orthographic processing has seldom been suggested in the literature owing to the predominant left-lateralized activation when phonological processing is inevitable in the experimental tasks, such as those that require character reading (Mei et al., 2015; Tan, Laird, et al., 2005; Wu et al., 2012). In fact, Jung-Beeman (2005) has aggregated experimental results that suggest a broad role for the RH in semantic processing regardless of language boundaries. His model, Bilateral Activation, Integration, Selection (BAIS), proposes that semantic knowledge is processed in both hemispheres in highly distributed networks (Jung-Beeman, 2005; McClelland & Rogers, 2003). The frontal part of these networks, especially the inferior frontal gyrus (IFG), is suggested to play a particular role in semantic selection (Jung-Beeman, 2005; Seger, Desmond, Glover, & Gabrieli, 2000). Consistent with this hypothesis, lexical-semantic deficits in meaning selection were found correlated with the RH lesions in specified frontal regions in a voxel-based lesion symptom mapping study (Y. Yang, Tompkins, Meigh, & Prat, 2015).

A meta-analysis of functional activation with different linguistic tasks by Vigneau et al. (2011) also resonates with the hypothesized RH orthography-semantics access. These authors concluded that more RH involvement occurs when phonology-related processes are minimized, as in lexical-semantic association and categorization tasks. Returning to the Chinese language, Han, Bi, Shu, & Weekes (2005) reported a case of a Chinese speaker with the diagnosis of dementia for 4 years whose CT scan showed a low-density focus in the posterior limb of the internal capsule of his LH. The patient demonstrated better character naming performance when the corresponding meaning could be retrieved. Chen and Yeh (2009) hypothesized that this facilitated naming was a neuropsychological indication of a preserved route in the RH connecting to semantics via orthography directly.

Other indications of the RH's involvement in semantics via orthography are exemplified in several neuroimaging studies of Chinese reading in which the meaning of characters could be accessed via orthographic processing at the level of the radicals. As mentioned in the beginning of this section, a RH-lateralized or bilateral response is evident when reading pseudocharacters (S. Chan et al., 2009; Lin et al., 2011; X. Wang et al., 2011; J. Yang, Wang, Shu, & Zevin, 2011; J. Yang et al., 2012), that combine two existing radicals which never occur together but each of which appears at a frequent position within other compound characters. Additionally, the RH was found involved in processing false or artificial characters consisting of one or two legal radicals in unusual positions (Lin et al., 2011; J. Yang et al., 2011, 2012). These experimentally designed characters do not possess corresponding pronunciation, and their phonological information can be even more complex than that of normal characters to determine during sublexical decomposition. On the other hand, though, some semantic information is accessible via their legal radicals which typically retain reliable meaning transparency (Jingjing Zhao et al., 2014). Still another indication of a RH-lateralized orthography-semantic route is implied from a MEG study (Hsu et al., 2011). The investigators found larger M170, which corresponds to N1 or N170 in ERP studies, in the RH when reading characters with low semantic combinability, or characters containing low-frequency semantic radicals. Because lower combinability indicates smaller orthographic neighbors and higher conditional probability, characters with lower semantic combinability tend to have more transparent meanings (Hsu et al., 2011; Hsu, Tsai, Lee, & Tzeng, 2009). The authors suggested that the RH's orthographic processing was influenced by the radicals' combinability when semantics was more transparent.

A RH-lateralized direct orthography-semantics route can also be inferred from a pattern shift in terms of hemisphere activation in some neuroimaging studies of Chinese reading. Based on investigations of different age groups of children as well as adult readers, there is evidence of a developmental shift through the acquisition of Chinese reading from LH-lateralized activation to bilateral activation. This shift has been observed to the bilateral middle occipital gyri from fMRI studies (F. Cao et al., 2009, 2010) and to more bilateral N1 than LH-lateralized responses around the same region in an ERP study (X. Cao, Li, Zhao, Lin, & Weng, 2011). In groups of children of increasing age, the lateralization shift became increasingly similar to the pattern for adult Chinese readers on tasks requiring less phonological processing. The trend from LH-lateralized to bilateral response might represent an increasing processing efficiency for orthographic analysis of Chinese characters to activate meaning during development (F. Cao et al., 2010; Song, Zhang, & Shu, 1995). Theoretically, this interpretation could be supported by the earlier finding that pediatric readers rely more on analysis of radical information than adult readers, who recognize characters as a whole (洪 et al., 2010). The ability to retrieve linguistic information from a compound character as a whole has been suggested to develop later in the stages of character reading. The acquisition of this ability has been described as the "orthographic stage" in the descriptive model of Ho et al. (2003).

At this point, based on the observations that the RH is more involved in processing characters when phonological processing is not required (e.g., M.-J. Yang & Cheng, 1999), the demonstrated RH involvement during lexical-semantic processing of the existing radicals (e.g., Hsu et al., 2011; J. Yang et al., 2012), and the fact that Chinese script can provide access to semantics through orthography directly without decoding phonology (e.g., Lee et al., 2006; X. Zhou & Marslen-Wilson, 1999), we hypothesize that an orthography-semantics route, with little interference from phonological processing, is represented in the RH. In particular, according to the converging findings, the hypothesis points that the RH becomes involved in reading Chinese characters for orthographic processing, undergirding the potential access to semantics (e.g., Jung-Beeman, 2005) beyond the complicated visual-word-form analysis (e.g., Perfetti et al., 2013). Thus, the current investigation hypothesizes that when a task requires mainly meaning activation, the processing of Chinese characters can attain the meaning via deciphering the orthographic structure of the character, and the RH is more proficient in the process when the meaning can be accessed without the need for phonological decoding.

2.3 STUDY OVERVIEW AND THEORETICAL IMPACT

Based on the importance of orthography in Chinese reading and writing, two hypotheses were proposed to explain the RH's processing preference for Chinese characters. The first hypothesis is that the RH contributes preferentially to the visual-word-form analysis of Chinese script, independently of the script's spatial frequency information. The second hypothesis proposes that the RH contributes preferentially to orthographic processing when semantics are accessed directly via orthographic structures of characters, bypassing phonological processing. This study aimed to investigate the RH's role in processing Chinese characters beyond the received wisdom that attributes it solely to visual-spatial processing for the word-forms themselves, exploring the potential of further down-stream semantic processing in the RH to access meaning via orthography.

The experiment for investigating the first hypothesis attempted to disentangle the relationship between low spatial frequencies and radical configurations in hemispheric specialization for Chinese character processing. The findings can potentially explain more specifically the mechanism of RH's preferential processing for radical configurations. By directly manipulating the radical configurations within a character, it is possible to interrogate the relationship between the RH and the radical configurations during character recognition processing regardless of the spatial frequency. Thus, the results of this study can broaden the implications for the suggested differentiation of these two visual constructs, radical configuration and low spatial frequency. If the results are as hypothesized, they could expand the claim regarding the RH's preferential involvement in character recognition from the domain of spatial frequency processing to the territory of spatial configuration of components.

The experiment designed to test the second hypothesis aimed to explore a neglected route from orthography to semantics which could also call on the RH's processing. Such direct access of semantics via orthography has been suggested (Perfetti & Liu, 2005), but the neural correlates have not been investigated from the standpoint of the hemispheric specialization. Regarding the activation observed beyond the posterior visual processing area, e.g., bilateral SPLs, Perfetti et al. (2013) suggest it represents the potential orthographic processing of morphosyllabic mapping. They attributed this result to a working memory module to sustain the visually complicated orthographic representations long enough to support character deciphering (F. Cao et al., 2009, 2010). The second hypothesis for the current study suggests another novel theoretical mechanism beyond the long-held view that the RH's involvement in Chinese character processing is limited to visual-spatial analysis. It is hypothesized here that an orthography-to-semantic route could be accessed by the RH when phonological information is minimally required. Again, these results have the potential to extend understanding of the role of the RH in language processes through the route of direct orthographic access to semantic information.

Overall, the findings from the two proposed experiments can each stand alone in terms of offering new elements in the theories of the RH's processing preference in language processing, and complement each other to extend knowledge regarding the RH's involvement in Chinese character recognition. The potential discussion that emerges from the interaction of the two hypotheses, for example, "does variety of radical configurations affect character meaning activation in the RH?" can produce supplemental theoretical indications to existing models, such as Lexical Constituency Model (Perfetti et al., 2005), for deciphering Chinese characters. The activation of the three linguistic constituents, orthography, phonology, and semantics, may not only differ in time course during Chinese character reading (Perfetti et al., 2013). The weight of activation for each constituent may also vary depending on the processes required, and the hemispheric lateralization may reflect such variation across different written scripts. The results of the current study can be used to elucidate the components modulating hemispheric differences in orthographic processing from the early visual-word-form analysis to the later access to semantics.

Down the road, by adding information to the models of hemispheric differences in language processing in a neurotypical populations, we are able to interpret further various neuropsychological findings. One example concerns the case of Chinese pure alexia and its claimed RH's involvement (Shan, Zhu, Xu, Luo, & Weng, 2010). Shan et al. (2010) reported a patient with lesions in the left occipito-temporal region and splenium who showed profound difficulty reading characters aloud. The patient presented with relatively intact implicit reading as measured by almost normal performance on lexical decision, and well above chance performance on picture-to-character matching, semantic categorization, and some levels of synonym matching. Considering our second hypothesis, the preserved RH may contribute to the processing in the above implicit reading skills through the proposed orthography-to-semantics route, while the damaged LH impedes the phonological processing required in decoding explicitly. It would be informative to know if there was a factor of radical configurations mediating the patient's reading performance from the standpoint of our first hypothesis. That is, the preserved implicit reading may indicate the RH's contribution in analyzing the orthographic structure of characters with certain radical configurations, but the damaged LH may interfere in the analysis of characters with the same radical configurations that have differences in detailed stroke arrangements.

2.4 METHOD: DIVIDED VISUAL FIELD PARADIGM

Divided visual field (DVF) presentation was used to investigate the hypotheses in this study concerning RH lateralization of processing for the visual-word-form analysis of the radical configuration of Chinese characters, and the orthographic processing of these characters to access semantics. DVF presentation has long been utilized to observe the potential processing asymmetries of the two cerebral hemispheres. The rationale of this method is that a visual stimulus presented to one visual hemi-field, or one side of a vertical line in the center of a visual field, is initially received and processed by the contralateral hemisphere (Beaumont, 1983; Bourne, 2006). That is, the RH receives and processes a stimulus presented in the LVF before it can be transferred to the LH, and the LH receives and processes a stimulus presented in the RVF first, before it is processed in the RH. If one hemisphere has the advantage in processing for a particular task, behavioral improvements can be observed in task performance, such as faster response times or greater accuracy, when that hemisphere processes the projected stimulus first. The information from the received stimuli is shared between the hemispheres via the corpus callosum and subcortical structures soon after contralateral projection. However, because the receiving hemisphere has the advantage of initiating the processing, and the other hemisphere only processes information filtered by the initiating hemisphere, the obtained behavioral improvements are suggested to result from hemispheric differences in processing proficiency (Bourne, 2006; Motz, James, & Busey, 2012).

For about half a century, DVF presentation has been applied as a reliable method to investigate hemispheric asymmetries in processing approaches for visual tasks, such as face recognition and word reading (see discussion in Beaumont, 2008). DVF presentation has also been utilized to explore hemispheric asymmetries in processing Chinese characters (e.g., Coney, 1998; Leong et al., 1985; Tzeng et al., 1979; M.-J. Yang & Cheng, 1999). The results show inconsistent hemispheric lateralization for this purpose. As alluded to earlier in this document, these mixed results could arise from the processing required in the experimental tasks (e.g. pronunciation judgment vs. meaning association) when deciphering the intricate composition of the Chinese characters. Another possibility is that these inconsistent findings may result from questionable manipulations of the stimuli. For example, Nguy, Allard, and Bryden (1980) found a RVF advantage for naming their single and combination characters, and no visual field difference for their pictorial characters. The problem is the single and combination characters in their study were actually not the simple or compound characters discussed earlier. Rather, the investigators classified compound characters with left-right radical arrangement as their combination characters, like "雄, xiong2, heroic" and "糖, *tang2*, candy," and compound characters with top-down radical arrangement as their single characters, like "貨, *huo4*, goods" and "堅, *jian1*, hard." Also, it is not clear how they classified their pictorial characters, such as "鬼, *guei3*, ghost" and "桌, *zhuo1*, table."

Overall, DVF presentation is applicable to demonstrate hemispheric asymmetries in processing with the benefits of easy and economical administration when compared with the neuroimaging modalities. DVF presentation was used to investigate the following research questions:

1. Does the RH contribute preferentially to visual-word-form analysis of the radical configurations in Chinese characters, independently of low spatial frequencies?

2. Does the RH contribute preferentially to semantic processing in accessing meaning directly via orthography, bypassing phonology?

3.0 METHODS

3.1 STUDY AIMS

This project was designed with two major aims. One was to investigate the prevalent hypothesis regarding the RH's preferential contribution to processing Chinese characters via visual-word-form analysis. The global configuration of these characters was systematically manipulated with three basic structures adopted from the work of Yeh et al (1997, 1999), including the left-right, top-to-bottom, and wrapped configurations. One goal of this aim was to examine the relationship between the RH and the analysis of the global configurations among the radicals. The other goal of this aim was to distinguish this relationship from the role of spatial frequency. The second aim was to investigate an overlooked hypothesis regarding the RH's preferential contribution to processing Chinese characters via a direct route from orthography to semantics. To test the hypothesized orthography-to-semantics route, the RH's contribution was investigated by manipulating the components/radicals within characters to exclude the involvement of phonological processing (Lin et al., 2011; X. Wang et al., 2011).

3.2 PARTICIPANTS

3.2.1 Participant Recruitment

All participants recruited for the two studies fulfilled the following criteria:

(1) Participants were undergraduate/graduate students primarily in the Pittsburgh area. They were mostly recruited via study recruitment posters and by referrals from colleagues or other participants.

(2) Participants were right-handed. Right-handedness is important for DVF studies to control for the higher chance of right lateralization effects for language developed among left-handed individuals (Young, 1982). Participants were included if they endorsed the use of the right hand on the six most discerning items on a handedness questionnaire (Annett, 1970). The six items were "Which hand do you use for: writing, throwing a ball, hammering, using a racket, dealing cards, using scissors." Using the method adopted in Townsend, Carrithers, and Bever (2001), familial handedness was also recorded, by participants' reports of family members who write left-handed, specifically for siblings, parents, parents' siblings, and grandparents.

(3) Participants' first language was Chinese and their primary written script was Simplified Chinese. They were included if they grew up speaking more than one of the Chinese languages, e.g. Mandarin and Shanghai-hua, but their formal education in written language took place in Simplified Chinese. They reported not growing up in a bi-/multi-lingual environment, except for Chinese languages. The acquisition of other non-Chinese languages, such as English, and the reported age of acquisition of those languages were recorded. Any acquired second language was not Korean or participants reported no knowledge of Korean written script. These criteria were

assessed by interviews with potential participants to screen their language background. The criteria were based on several rationales, including: a) the phenomenon that the varieties of Chinese spoken languages/dialects all share a common written script due to a common cultural heritage (Norman, 1988); b) studies show that the involvement of the RH is robust among native Chinese readers, not influenced by their proficiency in English (Liu et al., 2007; Nelson et al., 2009; Perfetti et al., 2007); c) Chinese readers in the target age group consistently classify the same radical configuration into one group (Yeh et al., 2003); and d) Korean written components were used in control filler items in the experiment.

(4) Per interview, participants did not have a medical history of developmental or acquired disorders affecting their vision or reading ability. Participants' vision was also screened with a perimetry test (Habekost, Petersen, Behrmann, & Starrfelt, 2014) to assess for any problems of visual perception in the lateral visual fields. The pass score was 90% accuracy. Their vision and reading ability were further screened by having them read aloud two sets of 10 words/characters, one set in English and the other in Chinese, presented in the lateral visual fields using the DVF method. English words were selected from vocabulary in first-year high school textbooks in Chinese-speaking countries (China and Taiwan). Chinese characters were selected from textbooks from the 5th and 6th grades. The grade level for each set of words/characters was chosen to assure participants' reading proficiency.

It was planned to recruit 25-35 participants to attain the estimated effect size (see Section 3.2.2, Estimated Effect Size and Sample Size). All participants performed both experiments. Participants were compensated for their time at a rate of 10 dollars an hour.

3.2.2 Estimated Effect Size and Sample Size

The estimation of effect sizes from previous studies was compromised by the limited number of projects designed with tasks similar or analogous to those in the current studies and the scarcity of available data for the estimation. In order to avoid the risk of underestimating the required sample size for this project, the value of the effect size (d=.326) for the power analysis was adopted from the most conservative estimation among previous studies (Coney, 1998). In a DVF study of character naming, Coney (1998) found a LVF/RH advantage for naming accuracy for characters with a small number of strokes (mean = 4.27) compared with a RVF/LH advantage for naming characters with medium (mean = 7.20) and large (mean = 11.45) numbers of strokes. The effect size of the LVF/RH performance was adopted as the estimate for the current studies. This was because characters with high stroke numbers are likely to be compound characters or phonograms[4] whose pronunciation can be indicated by the embedded radicals and the LH may be involved for the phonological processing while deciphering these characters. On the other hand, characters with fewer strokes may be mostly simple characters which do not contain a phonetic radical facilitating pronunciation for the LH. The number of experimental items, 40, was set together with the estimated effect size for obtaining the required sample size, 15, in the within-subjects design. Thirty-five participants were tested in order to capture an effect that may be even smaller (d=.20-.24).

[4] The stimuli sample/list was not provided in the study of Coney (1998).

3.2.3 Participant Characteristics

Demographic information about the 35 experimental participants is presented in Table 1. Prior to checking for sex differences in these characteristics, the assumption of normality was assessed for the three continuous variables (age; age of acquisition of English; education achieved in years). This was done because the sample size was smaller than 50 (McDonald, 2009). The alpha level for the normality tests was set to .05. According to the Shapiro-Wilk test and the distribution and probability plots (histograms, boxplots, and normal quantile plots), the age and education distributions were positively skewed (age: $W_{(35)} = .781$, $p < .0001$; education: $W_{(35)} = .806$, $p < .0001$). However, the age of English acquisition met the normality assumption ($W_{(35)} = .965$, $p = .326$). Nonparametric methods were adopted when the assumption of normal distribution was violated.

Table 1. Characteristics of the participants

Characteristics	Female	Male
Sex	24	11
Age (years)		
Mean (SD)	25.1 (8.3)	28.9 (9.5)
Range	18 – 49	18 – 48
Age of starting English learning (years)		
Mean (SD)	8.5 (3.6)	10.6 (3.3)
Range	3 – 15	6 – 16
Education (years)		
Mean (SD)	15 (3.1)	18 (5.1)
Range	12 – 24	12 – 24

Sex differences in these characteristics were examined by two-tailed statistical tests with an alpha level of .05. For age and education, the results of the Kolmogorov-Smirnov two-sample test were not significant (age: D_{max} = .337, asymptotic *p* = .358; education: D_{max} = .322, asymptotic *p* = .415), indicating there were no age or education differences between females and males. For age of acquisition of English, an independent sample *t*-test was used. The test for equality of variances was not significant ($F_{(23,10)} = 1.18$, *p* = .821), suggesting the assumption of homogeneity of variance was met. The pooled *t*-test was non-significant ($t_{(33)} = -1.56$, *p* = .128), indicating there was no difference in the reported age when the male and female participants started to learn English.

3.3 STUDY FOR QUESTION 1

Research Question 1. Does the RH preferentially contribute to visual-word-form analysis of the radical configurations in Chinese characters, independently of spatial frequency characteristics?

3.3.1 Stimuli for Study 1

Three basic orthographic structures were adopted from the work of Yeh et al (1997, 1999) for the radical configuration matching task as described further below (see Section 3.3.2). These are: (1) left-right/side-by-side forms, such as “明” “的” “伴”; (2) top-to-bottom forms, such as “昱” “胃” “吉”; and (3) inside-outside/wrapped forms, such as “困” “周” “匡.” The character stimuli were created in font PMingLiU, size 72. Each trial contained a pair of characters in which their radical configurations either matched or did not match. The two character stimuli from any trial did not reappear in any other combination. Table 2 illustrates the arrangement of the stimuli used in the experiment.

Table 2. Stimuli for Study 1

Experimental Trials	Filler trials
Match Trials (total = 40): Block1_(LR items 1-20) + (LR items 21-40) Block2_(LR items 41-60) + (LR items 61-80)	Match Trials (total = 40) Block2_(TB/W items 1-20) + (TB/W items 21-40) Block1_(TB/W items 21-40) + (TB/W items 1-20)
Mismatch trials (total = 40) Block1_(TB/W, items 1-20) + (LR items 21-40) Block2_(TB/W items 21-40) + (LR items 61-80)	Mismatch trials (total = 40) Block2_(LR items 1-20) + (TB/W items 1-20) Block1_(LR items 41-60) + (TB/W items 21-40)

Note. LR = Left-right configuration; TB/W = top-bottom or wrapped configurations.

3.3.1.1 Experimental Trials for Study 1

Each experimental trial had the left-right configuration for the second (target) character, and each target appeared in both a matching and mismatching condition. Responses to these trials provided the dependent variables in this study. The left-right configuration was selected as the form of interest because this configuration is the most common among existing characters (> 80%) and because focusing on one configuration avoided adding another factor (type of configuration) to the experimental design (to avoid lowering power). Several lexical factors were controlled; specifically, that the stimulus and target characters for matching could not combine into words in Chinese, that they did not share the same semantic and phonological radicals, and that their pronunciations were different. The use of any single radical was restricted to three occurrences.

Based on a power analysis, at least 40 experimental trials were needed in the experiment. The planned character combinations yielded 80 character pairs as experimental trials. Stimuli were built from 80 of the left-right configuration, 40 of the top-to-bottom, and 40 of the wrapped. Half of each configuration were used as the first character of a stimulus pair and the other half of each configuration was the target character of a pair.

3.3.1.2 Filler Trials for Study 1

Filler trials were generated from the same characters used in the experimental trials to make 80 character pairs whose target characters were either top-bottom or wrapped configurations. Half of the filler trials were matching pairs and the other half were mismatching pairs. The same lexical factors were controlled as in the experimental trials.

3.3.1.3 Spatial Frequency Manipulation

The resolution was blurred for half of the character target stimuli, and these were categorized as the stimuli containing low spatial frequencies. The other half were categorized as normal spatial frequency. Based on recent studies using low spatial frequency stimuli (e.g., Awasthi et al., 2011; Perilla-Rodríguez, de Moraes, & Fukusima, 2013), the blurring process was accomplished using MATLAB (The MathWorks, Inc.). The images of the selected character stimuli were Fourier-transformed and multiplied by a low-pass Gaussian filter to preserve low spatial frequencies. For a 2-D space with an x-axis and a y-axis, a Gaussian-shaped convolution kernel was formed for the corresponding shape of the filter. The filtered images were then inverse-Fourier-transformed. The standard deviation or delta (δ) of the filter was set to eight and the image size was 128x128 in pixels. Figure 1 demonstrates an unfiltered character in its normal spatial frequency and that character filtered in the low spatial frequency.

Figure 1. An unfiltered character in normal spatial frequency (left); a character filtered in low spatial frequency (right)

3.3.2 Task for Study 1

The radical configuration matching task was administered using the DVF method. Participants were asked to decide if a target stimulus' radical configuration, presented in either the RVF or the LVF, matched the preceding stimulus' configuration, presented in the center of vision. Half of the trials required a response of "yes," and the other half required a response of "no." For each trial of the matching task, a fixation cross appeared for 700 ms in the center of the screen. Participants were reminded explicitly to keep their gaze on the point of the fixation cross throughout the experiment. Then a Chinese character appeared in the center of the screen for 200 ms. Following a blank screen for 300 ms, a different Chinese character appeared in either the RVF or the LVF for 200 ms. Participants were asked to press a response button labeled "yes" if the two characters contained the same radical configurations, or another response button labeled "no" if the two characters contained different radical configurations (for specific instructions, see Appendix A.1 and A.2). The next trial started after the participant made a response or after 3500 ms (Chiarello, Liu, Shears, Quan, & Kacinik, 2003).

The central presentation for the first stimulus was designed to minimize the potential inter-hemispheric transmission of the perceived information. If the first character was presented to either of the lateral VFs, e.g., the left one, due to the interhemispheric information transmission via the corpus callosum, the information received and processed initially in the RH would be transmitted to the LH and the LH would process that information after receiving it. Such interhemispheric transmission and processing take place inevitably. When the second character is presented to the LVF, projected to the RH for initial information processing, the information from the first character for the matching task might be processed/analyzed by the LH, which could possibly confound the matching performance. On the other hand, if the first character was presented to the center, as planned, both RH and LH would receive and process the information at relatively the same time. Thus, when the second character was projected to the LVF/RH, the matching task could be performed with less potential interference from interhemispheric transmission and processing. The presentation time for the fixation cross (700 ms) was determined based on previous DVF studies in Chinese character reading (e.g., Coney, 1998; Leong et al., 1985). The presentation time of 200 ms for the stimuli was chosen to minimize the possibility that the lateralized stimuli were foveated by the eyes, diminishing the unilateral presentation (Bourne, 2006). Also, based on ERP studies, the index of object recognition, N170 or N1, has been observed to reach its peak at around 150 to 200 ms, indicating successful visual registration of a specific object (e.g., Gauthier, Curran, Curby, & Collins, 2003; Rossion et al., 2003; Tanaka & Curran, 2001). The blank screen (300 ms) in between stimuli was applied as a backward visual mask to reduce afterimage effects (Bourne, 2006). Potentially, an afterimage may functionally extend the presentation duration.

Half of the experimental and filler trials were administered in the first half of the session as the first block of the experiment, and the rest were administered in the second half. Each block contained equal numbers of matching and mismatching trials, and equal numbers of each of the three orthographic forms. Items within each block were pseudorandomized with the condition that no more than three matching or mismatching trials occurred in sequence. No more than three consecutive target characters were presented in the same lateral field. The sequence of the two blocks was counterbalanced among participants.

3.3.3 Practice for Study 1

To initiate the practice session the three radical configurations were introduced, with three sample characters for each. The practice session had three parts. In each part, participants were asked to maintain their gaze on a fixation cross that preceded each practice item. (A detailed description of the fixation procedure is provided below).

The first two parts of practice were administered to ensure that participants understood the experimental task. Participants were asked to decide if each of nine centrally-presented characters belonged to one of the three radical configurations after fixating their eyes on the fixation cross. The second part of practice was five items of the matching task presented in the central visual field after fixation. Understanding of the task was indicated by achieving an average of 90% accuracy for each part of practice with the eyes appropriately fixated. If the 90% criterion was not attained, the participant was asked to redo these two parts of practice using another 10 items with different characters.

The third part of practice was 20 items of the matching task using the experimental DVF presentation method. A minimum of 75 percent accuracy was required, based on precedent DVF studies in character reading (e.g., C.-M. Cheng & Yang, 1989; M.-J. Yang & Cheng, 1999; Zhang & Peng, 1983). If the 75% criterion was not achieved, the participant was asked to redo the practice using the same items in a different randomized order. The RTs to accurate practice items were plotted immediately by the investigator, and if the 75% accuracy criterion was achieved, the RTs were checked to see when they began to stabilize. RTs were determined to stabilize when the range of RT variation for the last 10 accurate items was within 500 ms. If this RT variation criterion was not achieved the participant was asked to perform the practice task again, with the items in another randomized order. This extended practice was intended to stabilize the learning curve for the task. If the RT variation criterion was not achieved within thirty minutes of the start of the Practice session, twice the projected timeframe, the participant was excluded.

The fixation process was initiated with a black fixation point, a cross (Arial, 20-point font), presented for 450 ms in the center of the screen. At the same fixation position, the black cross became red for 100 ms, and then turned back to black for 150 ms. The color change was designed to facilitate central fixation as suggested by Chiarello et al. (2003). Five fixation control items were interspersed in each part of the practice session. In these items, after the fixation cross disappeared, a small numeral was displayed for 200 ms in the center of the visual field, and participants were asked to press yes button for an odd number and no button for an even number. This number could only be perceived if the participant fixated the central fixation point (Young, 1982). When participants identified these numerals correctly, it could be inferred that they had focused on the central fixation point.

3.4 STUDY FOR QUESTION 2

Research Question 2. Does the RH contribute preferentially to semantic processing in accessing meaning directly via orthography, bypassing phonology?

3.4.1 Stimuli for Study 2

This experiment utilized a primed lexical decision task with pseudocharacter primes and target stimuli which were either characters or noncharacters, as described further below. The stimuli were in font type PMingLiU, size 72. Photoshop was used to generate the stimuli for this experiment. Table 3 illustrates the stimuli presented in one block of the experiment.

Table 3. Stimuli for one block of Study 2

<table>
<tr><td colspan="4">Block 1 – 140 Trials</td></tr>
<tr><td colspan="4">Experimental Trials (20 trials)</td></tr>
<tr><td colspan="2">LVF: 10 trials</td><td colspan="2">RVF: 10 trials</td></tr>
<tr><td>S Prime (5)</td><td rowspan="2">Experimental targets (10)</td><td>S Prime (5)</td><td rowspan="2">Experimental targets (10)</td></tr>
<tr><td>SP Prime (5)</td><td>SP Prime (5)</td></tr>
<tr><td colspan="4">Filler Trials (60 trials)</td></tr>
<tr><td colspan="2">LVF: 30 trials</td><td colspan="2">RVF: 30 trials</td></tr>
<tr><td>S Prime (5)</td><td rowspan="3">Filler targets (30)</td><td>S Prime (5)</td><td rowspan="3">Filler targets (30)</td></tr>
<tr><td>SP Prime (5)</td><td>SP Prime (5)</td></tr>
<tr><td>Filler primes (20)</td><td>Filler primes (20)</td></tr>
<tr><td colspan="4">Non-character Target Trials (60 trials)</td></tr>
<tr><td colspan="2">LVF: 30 trials</td><td colspan="2">RVF: 30 trials</td></tr>
<tr><td>S Prime (5)</td><td rowspan="3">Non-character targets (30)</td><td>S Prime (5)</td><td rowspan="3">Non-character targets (30)</td></tr>
<tr><td>SP Prime (5)</td><td>SP Prime (5)</td></tr>
<tr><td>Filler primes (20)</td><td>Filler primes (20)</td></tr>
</table>

Note. LVF = Left Visual Field; RVF = Right Visual Field; S = Semantics; SP = Semantics and Phonology

3.4.1.1 Experimental Trials

Pseudocharacters were used as primes for this study. Two types of the pseudocharacters were generated. The first type consisted of a semantic radical which cannot stand alone or be pronounced, such as 氵, meaning “water,” and a Korean alphabet component, such as 려, combined to yield “氵려.” Ten non-stand-alone semantic radicals were used, which were “氵, water,” " 忄, heart” ” 扌, hand,” ” 犭, dog,” ”⺮, bamboo,” “饣, eat/food,” “疒, sick,” “衤, clothes,” “礻, related to religious/spiritual events,” and “钅, metal.” These radicals were selected based on their high semantic transparency when embedded into compound characters and the fact that their semantic categories were distinct from each other. A word has semantic transparency when it has meaning synchronized with its morphological components (Marslen-Wilson, Tyler, Waksler, & Older, 1994). For example, in English, semantically transparent words are *happiness* or *milkman*, and semantically opaque words are *department* or *butterfly*. In Chinese, semantically transparent characters are compound characters, typically phonograms, whose semantic radicals provide a transparent meaning link to the compound (Lee et al., 2006; 陳, 張, 邱, 宋, & 張, 2011). Semantic transparency data for Chinese characters are available in the database of 陳 et al. (2011). Semantic transparency in this database is calculated as the number of characters containing the designated radical and using its meaning divided by the number of all characters containing the designated radical. The mean semantic transparency of the non-stand-alone radicals in this study was 95% (range from 88% to 100%). Each semantic radical was used to produce four pseudocharacter primes which were designated ‘semantics only’ primes or S primes. The 10 radicals were combined with 40 Korean components to create 40 pseudocharacters as the S primes for this experiment. The second type of pseudocharacters was generated by using the radicals orthographically derived from the 10 non-stand-alone semantic radicals, which have the same meaning as their non-stand-alone correspondents but also have phonological information that allow pronunciation even when standing alone as characters. Therefore, the second type of the pseudocharacters served as ‘semantics and phonology’ primes or SP primes. There were 40 SP primes made by combining those 10 stand-alone radicals with 40 Korean components.

The Korean alphabetic components used in the S and SP primes, such as “려,” were composed of two parts, a consonant symbol, “ㄹ” and a vowel symbol, “ㅕ.” There are 140 basic combinations of the consonants and the vowels in the Korean alphabet. The 80 used in the pseudocharacters were selected randomly.

Target characters for the lexical decision task, such as “魚, *yu2*, fish,” were all non-phonograms, in which radicals do not provide phonological information about the characters’ pronunciation. The targets did not contain any of the non-stand-alone or stand-alone radicals used as S or SP primes. For each of the 10 semantic radicals in the pseudocharacter primes, four non-phonogram targets were chosen. These 40 target characters were paired with either S or SP primes to form experimental trials which satisfied the result of the power analysis for the experiment. The radicals/characters embedded in the primes and the target characters did not form words. The targets were chosen to have a meaning association with the primes, one that was designed to be weak. The weak semantic association was selected due to the trend in the literature (e.g., Deacon et al., 2004; Jung-Beeman, 2005; Reilly, Machado, & Blumstein, 2015) that the LH tends to respond to words with strong semantic associations, and the RH tends to respond to words sharing distantly related semantic features. A strong association may arise from word pairs in the same semantic category (e.g., coffee-tea in E. R. Smith, Chenery, Angwin, & Copland, 2009) or in different ones (e.g., thread-sewing in Bouaffre & Faïta-Ainseba, 2007; bees-honey in Deacon et al., 2004). The word pairs with overlapping semantic features but not strongly associated with each other usually come from the same category (e.g., honey-glue in Bouaffre & Faïta-Ainseba, 2007; mosquito-flea in Grose-Fifer & Deacon, 2004). This trend has been suggested to indicate theoretical hemispheric differences in terms of semantic knowledge networks, such that LH's network is relatively local for fine coding and RH's is more distributed for coarse coding.

Hence, for the primes and targets in the primed lexical decision task, the semantic relationship between primes and targets was not based on strong association but rather on sharing semantic features. A traditional large-sample free association piloting session was considered to verify prime-target relationship, but this idea was rejected because of several concerns: 1) Due to the transparent semantic relationship between the semantic radicals and the characters containing those radicals in Chinese, most characters embedded with those radicals would be strongly associated to the meaning of the radicals and be easily prompted through a free association task; 2) The free association procedure might be able to verify an obvious semantic relationship but it might have limited function to generate the intended targets for the experimental design; and 3) Participants in the pilot session would have to be excluded from the experimental study itself, reducing the number of available, eligible experimental participants.

Instead, four people were asked to do the free association task. These participants' first language was Chinese and primary written script was Simplified Chinese, as determined by self-report. They were eligible if they grew up speaking more than one of the Chinese languages, e.g. Mandarin and Shanghai-hua, but their formal education in written language took place in

Simplified Chinese. They did not have medical history of developmental or acquired disorders impacting their language skills, per self-report. During the free association task, these four individuals were asked to produce the first characters they thought of in one minute after reading the radicals embedded in the experimental primes (S and SP). No examples were provided to encourage the production of strongly associated characters in their natural semantic network. Based on these responses, the investigator consulted with a Chinese linguist to generate the targets. First, the targets were not among any of the free association responses which were likely to be strongly associated with the semantic radicals in the primes. Then it was determined that the targets could not form frequent words with the primes, but were still related to the radicals embedded in S and SP primes.

3.4.1.2 Filler Trials

The relatedness proportion for the lexical decision task was set to 25%, which defined the proportion between the experimental trials which had the prime-target relationship and the filler trials. Hence, with 40 experimental trials, 120 filler trials were needed. These trials were generated to disguise the relationship between experimental primes and targets. These trials were assembled with 20 S primes, 20 SP primes, and 80 filler primes, paired with 120 filler targets.

Filler primes were Korean characters consisting of three components, such as 렘. These Korean characters are more complex in terms of the visual-spatial layout than the Korean components embedded in the experimental prime pseudocharacters. Therefore, the Korean characters acted as filler primes with similar visual-spatial layout to Chinese characters but without carrying linguistic information for people who do not speak Korean. The 120 filler targets were Chinese characters, not restricted to nonphonograms, with meaning different from the experimental primes and pronunciation different from the experimental targets.

3.4.1.3 Non-character Target Trials

The nonword (noncharacter) ratio was set to 50%, which defined the proportion of the noncharacter targets needed in the experiment. Thus, 120 non-character target trials were generated. The noncharacter targets were generated by combining two radicals which never come together to form a character and putting at least one of the radicals in an illegal position. These trials were assembled with 20 S primes, 20 SP primes, and 80 filler primes.

3.4.2 Task for Study 2

A primed lexical decision task was administered using the DVF method. A RH processing preference in the lexical decision task, while deciding the lexicality of the Chinese characters, has been observed in neuroimaging studies (Hsu et al., 2011; J. Yang et al., 2012) and in a neuropsychological case study (Shan et al., 2010). Participants in the current experiment were asked to decide whether a stimulus was a real Chinese character or not after being primed by a pseudocharacter (S or SP primes) or a control Korean hangul/character.

In each trial, the color-shifting fixation cross appeared for 700 ms in the center of the screen (Chiarello et al., 2003). Then a prime appeared in either the LVF or the RVF for 200 ms. Following a blank screen for 300 ms, a Chinese character or character-like image appeared in the center of the screen for 200 ms. Participants were asked to decide if the second image was a real character as quickly and accurately as possible (Appendix A.4 contains specific instructions).

The target characters were presented in the center of vision to minimize the potential inter-hemispheric transmission of perceived information if presented in either visual field. Such information transmission might interfere with the hypothesized priming effect via the exposure of the preceding pseudocharacters. If the target was presented to the lateral VF, too, e.g., the LVF, the inevitable interhemispheric transmission and processing might again take place and potentially confound the induced priming effect during the lexical decision task. With the current method of presenting the target to the center of vision, both RH and LH would receive and process the input at almost the same time, and the lexical decision would reflect more specifically the priming effect of interest without the add-on interhemispheric transmission and processing.

Half of the experimental, filler, and noncharacter trials were administered in the first half of the session as the first block, and the rest were administered in the second half. Each block contained equal numbers of experimental, filler, and non-character trials and equal numbers of each of the pseudocharacter primes. Items within each block were pseudorandomized with the condition that no more than three experimental or filler trials occurred in sequence. No more than three consecutive primes were presented in the same lateral field. No more than three consecutive trials required the same response.

3.4.3 Practice for Study 2

There was also a multi-part practice session before the experimental task for Study 2 (see Appendix A.3 for instructions). The practice followed the same procedures as those for Study 1 in terms of session structure, fixation requirements, accuracy criteria, judgment of RT asymptote, and repetition of practice or exclusion from the study. In the first part of the practice session, five items were presented centrally for lexical decision, preceded by the fixation cross. This was followed by five items of centrally presented primed lexical decision, in which each item included the fixation cross, a prime, and a target character, with display durations identical to those in the experimental lexical decision items. The primes for the practice were all random line arrangements, created by combining part of a radical with a Korean component and arranging them in different orientations from the originals. For this part of the practice session, participants were told to decide if the second stimulus after the cross was a real character. Three fixation control items were interspersed in each of these first two parts of the practice session. Participants were instructed that they needed to make their decision on the target characters and ignore any others they might perceive, maintaining good central fixation. They were not informed of the nature of the priming condition embedded in the task. The final part of practice was 20 items of the primed lexical decision task presented in the DVF format used for the experimental task. There were five fixation control items interspersed adopting the same screening protocol as in Study 1.

3.5 PROCEDURE

3.5.1 Administration of Experiments

The study began with confirming the participants' eligibility, as outlined in Section 3.2, and obtaining informed consent. Participants were tested individually in a quiet room with dimmed lighting. Participants sat down, put their heads on a chin rest, and adjusted their bodies to a comfortable position. Every participant took part in both studies. The sequence of the experiments and of the blocks within each experiment was counterbalanced across the participants. Each experiment lasted about 15-20 minutes with short breaks between the two blocks of each study and between the two studies. Participants used only the index finger of their right hand to respond.

3.5.2 Apparatus

Stimuli were presented on a laptop screen (Dell Inspiron 5150 notebook). The stimuli presented in either visual field were allocated 3° of visual angle from the central fixation to diminish the potential overlap of the ipsilateral and contralateral projections and to ensure unilateral perception (Beaumont, 2008; Bourne, 2006). The outmost edges of the stimuli did not pass 5° laterally from the fixation. Participants were seated in front of the screen at a distance of 60 cm following the method used by Fassbinder (Fassbinder, 2006), to maintain the planned visual angle from their eyes to the unilaterally presented stimuli. E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA) was used to coordinate stimulus presentation and collect data. A chin rest was used to maintain a constant distance between the participants' eyes and the monitor, for controlling the visual angle of the stimuli presentation.

Manual yes/no responses were recorded by a response box (Serial Response Box, Psychology Software Tools), with response button assignment counterbalanced between participants. For half of the participants, button 2 was assigned to no-responses, and button 4 to yes-responses; for the other half of participants, the opposite assignments was made. Button 3 was a ‘home base’ on which participants rest their response finger between trials.

3.6 STUDY DESIGN AND HYPOTHETICAL OUTCOMES

Study 1, using the Radical configuration matching task, had two predictor variables, each with two levels (Visual field of presentation: RVF, LVF; Spatial frequencies: Low, Normal). Only the performance on target left-right configurations was analyzed. Based on the hypothesis of Research Question 1, the factor of visual field presentation was expected to have a main effect on the performance of radical configuration matching, in that the performance (Accuracy and RT) would be better in the LVF/RH. There would also be a main effect of the spatial frequencies, in that the performance would be worse for the stimuli with low spatial frequency. It was hypothesized that performance would be better for the targeted left-right configurations presented to the LVF/RH, where the visual analysis of radical configurations is lateralized, than for the same configurations presented to the RVF/LH. In addition, if the two hemispheres process Chinese characters’ spatial configurations and spatial frequencies as two perceptual entities (i.e., independently), there would be an interaction of visual field and spatial frequency on matching performance. The interaction would be demonstrated by a significantly different matching performance for normal and blurred stimuli presented to the LVF/RH, such that either those with normal spatial frequency or with low spatial frequency would be processed more accurately and/or faster.

Study 2, using the Primed lexical decision task, also had two predictor variables with two levels each (Visual field of presentation: RVF, LVF; Prime type: S and SP). Based on the hypothesis of Research Question 2, there would be an interaction of visual field and prime type. Between the two types of primes, the S primes would facilitate the RH's processing, reflected by performance with LVF presentation of the real character target, and the SP primes would facilitate the LH's processing, with presentation of the real character target in the RVF. These hypothetical outcomes were derived from the theories of LH's obligatory phonological processing and the hypothesized orthography-semantic route in the RH, the RH's involvement during the lexical decision task in neuroimaging studies (Hsu et al., 2011; J. Yang et al., 2012) and a neuropsychological case study (Shan et al., 2010), and the findings in neuroimaging studies of pseudocharacter processing in non-linguistic-based tasks (e.g., S. Chan et al., 2009; Lin et al., 2011). S. Chan et al. (2009) used fMRI and asked their participants to perform a synonym judgement of a pair of Chinese characters, and a physical judgment (identical vs. non-identical) of a pair of pseudocharacters and of Korean characters. Lin et al. (2011) used ERP and asked their participants to compare the color of the target stimulus, including real characters, pseudocharacters, false characters, and stroke combination. They found that the LH responded to pseudocharacters containing radicals that can stand alone in illegal positions which potentially allow possible sublexical phonological and semantic processing. The RH involvement was not restricted to this condition, in that the RH responded to the pseudocharacters as long as they contained legal radicals, including those radicals that cannot stand alone.

Inspired from the neuroimaging results, alternatively, there could be a main effect of visual field such that both prime types facilitate lexical decision in the LVF/RH presentation and an interaction between the visual fields and prime types such that SP primes facilitate the lexical decision in the RVF/LH presentation. Theoretically, this alternate outcome requires some specific structure in terms of the lexical constituents (see Perfetti et al, 2013 for details), orthography, phonology, and semantics. The difference between S primes and SP primes was whether the phonological information was embedded in the pseudocharacters. This particular alternate outcome suggests that the RH takes advantage of the semantic information from the stand-alone radicals embedded in SP primes as it does with S primes. The results from a primed naming study (X. Zhou & Marslen-Wilson, 1999) and a ERP study assessing the N400 response (Lee et al., 2006) suggested automatic sublexical processing with the radicals' both phonological and semantic representations, even when that information was different from or irrelevant to the resultant characters'. However, it is unclear how the automatic sublexical phonological information would facilitate or interfere with the performance of lexical decision when it was activated first in the LVF/RH which is not specialized for phonological processing. If the facilitatory effect was observed with SP primes in the LVF/RH presentation, it could suggest that sublexical phonological information is irrelevant for the RH in the lexical decision process. Facilitation via SP primes could occur via the hypothetical direct orthography-to-semantics route, bypassing phonology in the RH.

3.7 DATA ANALYSIS AND DIAGNOSTIC PROCEDURES

The Statistics Analysis System (SAS) software was used for data analysis. Participants was set as a random variable, and the two predictors in each study were set as fixed variables. Dependent measures were primarily accuracy and secondarily RT (for accurate responses) for radical configuration matching in Study 1 and primed lexical decision in Study 2. Accuracy was selected as the primary outcome because the DVF task can reduce participants' accuracy to a point that there would be too much data loss for a valid or meaningful analysis of RTs (Atchley, Burgess, & Keeney, 1999; Young, 1982). Accuracy and RT were analyzed separately. The alpha level was set to .05 for two-tailed statistical testing in both studies.

For the accuracy dependent measure, Generalized Linear Mixed Modeling (GLMM) was adopted to fit with the binominal distribution with the logit link function, which specifies the relationship between the mean of the outcome variable and the linear predictor (Schabenberger, 2005). The ridge-stabilized Newton Raphson algorithm was selected as the optimization technique for the binary outcome measure (J. Wang, Xie, & Fischer, 2012).

For the RT dependent measure, normality was examined in several ways, including visual inspection of the residual distribution and probability plots, the Kolmogorov-Smirnov test, and the skewness value. The assumption of normality was violated for both studies. For Study 1, the Kolmogorov-Smirnov value was .166 ($p<.01$) with positive skewness (3.37). For Study 2, the Kolmogorov-Smirnov measure was .157 ($p<.01$), again with positive skewness (3.86). Homoscedasticity of the residuals was also checked for the RT outcome measure and it was violated for both studies ($p<.0001$). Thus, the GLMM procedure was also adopted for RT analyses, as a non-parametric method of analysis (J. Wang et al., 2012). The gamma distribution and the inverse Gaussian distribution were chosen as the candidates to fit the models for the RT measures, which were non-negatively continuous by nature and positively skewed in both studies (Anderson, Verkuilen, & Timothy Johnson, 2010). Log link was adopted owing to the positive nature of the RT measures. A dual Quasi-Newton optimization technique was used in parameter estimation. The Laplace approximation method, a numerical integration to approach maximum likelihood estimation, was used as the primary estimation procedure. The deviance statistics provided by this approach, Akaike's information criterion (AIC) and Bayesian information Criterion (BIC), were used for selecting the distribution (gamma vs. inverse Gaussian) during model fitting for the RT measures (J. Wang et al., 2012).

Several demographic characteristics were selected for theoretical and empirical reasons as control variables, including age, age of acquisition of English, education, familial handedness, and sex. In addition, an individually proportionalized measure of RT variation during practice was included as a control variable in the RT analysis for both studies. This measure was calculated from the trial when the RT variation criterion was attained, by averaging the percentage of change from the previous item for the last 5 accurate items in the final part of the practice session. The RT variation criterion for Study 1 practice was 500 ms RT range for the last 10 items and for Study 2 it was 350 ms RT range. The criteria were determined with the observation from the test runs with five pilot participants that given one single trial, their average RT for the last 10 correct items during practice for Study 1 was longer than the average RT for Study 2 (Study 1: mean = 1105.16, SD = 222.44; Study 2: mean = 539.24, SD = 127.73).

Sex differences were also examined by two-tailed tests ($\alpha = .05$) for RT variation during practice, and the number of trials of the final part of the practice session taken by each participant to attain the RT criterion. First, the assumption of normality was checked for these variables. Non-normal distributions were evident for three of these measures: RT variation in Study 1 practice (W = .899, p = .004, positively skewed), the number of trials taken in the final part of practice to attain RT variation criterion for Study 1 (W = .901, p = .004, positively skewed), and the same variable for Study 2 (W = .848, p < .000, positively skewed). The RT variation for Study 2 practice met the normality assumption (W = .964, p = .297). The Kolmogorov-Smirnov test indicated that there were no sex differences in the RT variation in Study 1 practice session (D_{max} = .212, p = .887), the number of practice trials taken for Study 1 to attain RT variation criterion (D_{max} = .205, p = .911), and the same variable for Study 2 (D_{max} = .235, p = .80). The assumption of homogeneity of variance was met for the RT variation in Study 2 practice ($F_{(10,23)}$ = 1.4, p = .485). The independent sample *t*-test indicated no sex differences in the RT variation in Study 2 practice (pooled $t_{(33)}$ = -.073, p = .473).

Subsequently, the Wilcox signed rank test, a non-parametric alternative to the paired *t*-test, was used to examine if there were any differences between Study 1 and 2 in either the RT variations or the number of practice trials to attain the RT variation criterion. These analyses were conducted because in the Chinese education system, radical configurations are only introduced briefly at the beginning of elementary school, and not explicitly reviewed in the curriculum afterwards. Students are able to apply knowledge of radical configurations to classify the similarity in visual forms of the Chinese characters (葉, 林, & 李, 2004) along with their accumulated acquisition of the written characters by the academic years in elementary school. This background raised a question about the potential interpretation of the participants' RT performance on the radical configuration matching in Study 1, which requires the implicitly acquired knowledge that is tapped in the lexical decision task in Study 2. No difference in RT variation was evident between practice in Study 1 and 2 (S = -2, p = .974). There was a difference in the number of practice trials taken to attain the RT variation criterion for Study 1 and 2 (S = 144, $p = .003$), with participants taking more trials for Study 1. This suggests participants might not be as adept with the processes required for radical configuration matching as they are with those for lexical decision.

4.0 RESULTS

4.1 STUDY 1 FOR RESEARCH QUESTION 1

Study 1, using the radical configuration matching task, investigated the research question, does the RH contribute preferentially to visual-word-form analysis of the radical configurations in Chinese characters, independently of low spatial frequencies? Table 4 reports the descriptive information for accuracy and RT. GLMMs were used to analyze participants' performance for both outcome variables (see Table 5 for statistics). The two predictors, visual field and spatial frequency, were analyzed separately for main effects, and then altogether with their interaction term included.

Table 4. Descriptive data for accuracy and response time (for accurate responses) in Study 1

Visual Field Spatial Frequency	Accuracy proportion Mean (SD) Range	Response Time (ms) Mean (SD) Range
Left (RH) Low, Blurred	0.98 (.15) 0 – 1	539.19 (219.20) 182 – 1955
Left (RH) Normal	0.99 (.12) 0 – 1	521.73 (220.11) 181 – 2383
Right (LH) Low, Blurred	0.98 (.13) 0 – 1	506.35 (178.12) 178 – 1240
Right (LH) Normal	0.97 (.17) 0 – 1	555.31 (218.67) 161 – 1881

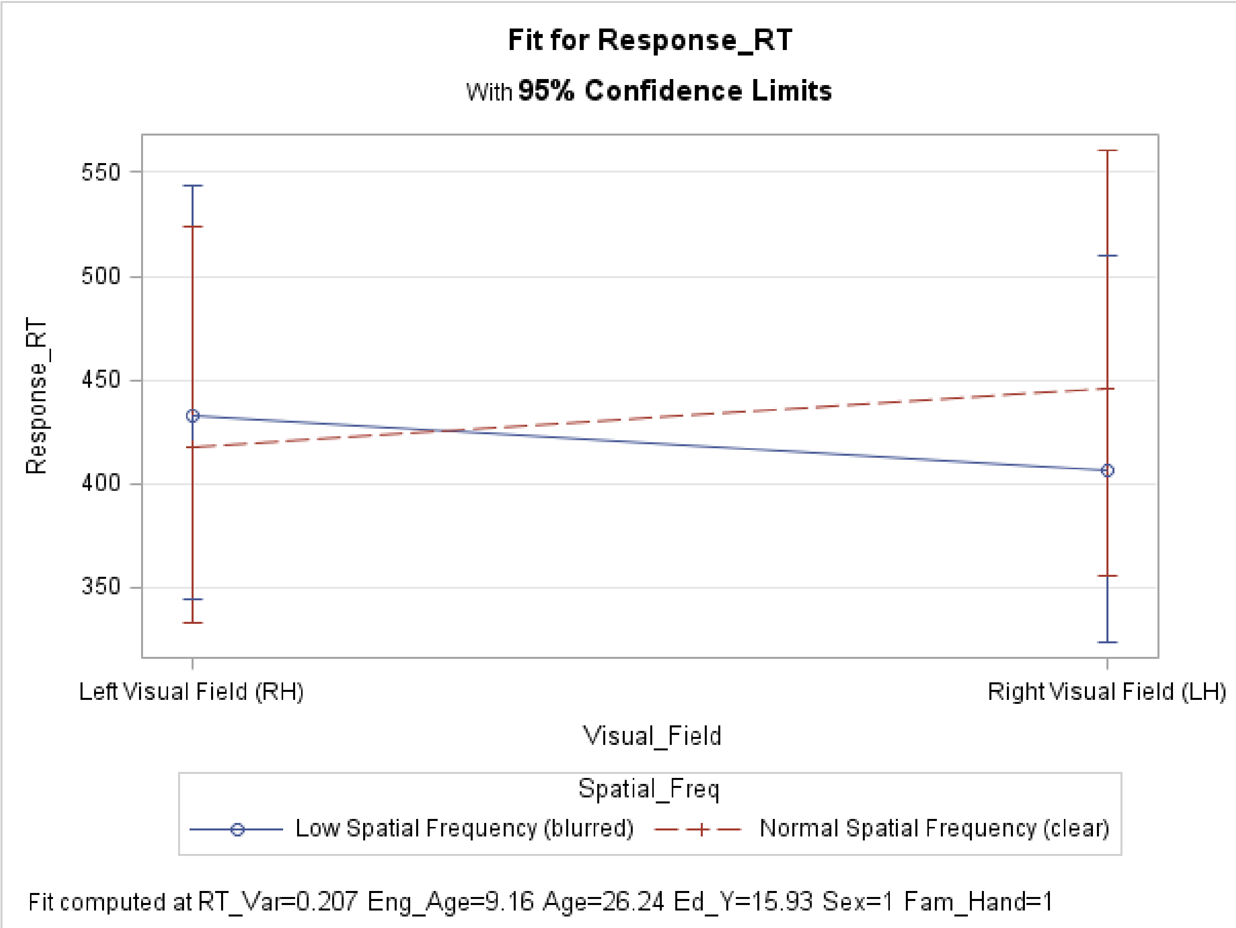
Note. RH = Right Hemisphere; LH = Left Hemisphere; ms = milliseconds

Table 5. Effects of visual field, spatial frequency and their interaction

	Estimate	SE	t-value	df	*p*	CI
Accuracy						
Visual Field	-.184	.270	-.680	34	.502	[-.733, .366]
Spatial Frequency	.015	.269	.060	34	0.955	[-.532, .562]
Visual Field × Spatial Frequency	-1.016	.552	-1.84	34	.074	[-2.137, .105]
Response Time						
Visual Field	.004	.011	.360	34	0. 722	[-.018, .026]
Spatial Frequency	.016	.011	1.48	34	0.15	[-.006, .038]
Visual Field × Spatial Frequency	.131	.022	6.04	34	.000	[.087, .175]

For the accuracy analysis, there were no main effects of either predictor variable on radical configuration matching (visual field: $t_{(34)} = -.68$, $p = .502$; spatial frequency: $t_{(34)} = .06$, $p = .955$). There was also no significant interaction between the two predictors (visual field × spatial frequency: $t_{(34)} = -1.84$, $p = .074$). None of the control variables showed significance throughout the analyses. In the final model of interaction, the statistics for these control variables were age: $t_{(28)} = -1.33$, $p = .194$; age of acquisition of English: $t_{(28)} = -.35$, $p = .729$; education: $t_{(28)} = .92$, $p = .365$; familial handedness: $t_{(28)} = .3$, $p = .769$; sex: $t_{(28)} = .12$, $p = .905$; RT variation during the practice session: $t_{(28)} = 1.23$, $p = .23$.

For RT, there were no main effects for either predictor (visual field: $t_{(34)} = .36$, $p = .722$; spatial frequency: $t_{(34)} = 1.48$, $p = .15$). There was, however, a significant interaction (visual field × spatial frequency: $t_{(34)} = 6.04$, $p = <.0001$). The fixed-effect estimates for this significant result were visual field = -.064, spatial frequency = -.036, and visual field * spatial frequency = .131. Figure 2 contains the plot of this interaction, showing that when the matching targets were presented in the RVF/LH, RTs were longer for those with normal spatial frequency (not blurred) than with low spatial frequency ($t_{(34)} = 5.59$, $p < .0001$). By contrast, in the LVF/RH presentation condition, RT was significantly slower in the blurred (low spatial frequency) condition than for the normal spatial frequency items ($t_{(34)} = -2.61$, $p = .013$). These results suggest that the radical configurations and spatial frequencies could be processed as two perceptual entities. Again, none of the control variables showed significance throughout the analyses. In the final model of interaction, the statistics for these control variables were age: $t_{(28)} = .62$, $p = .54$; age of acquisition of English: $t_{(28)} = -.06$, $p = .949$; education: $t_{(28)} = .16$, $p = .878$; familial handedness: $t_{(28)} = .97$, $p = .338$; sex: $t_{(28)} = 1.88$, $p = .071$; RT variation: $t_{(28)} = -.61$, $p = .548$.



Note. Ed_Y = Education in years; Eng_Age = Age of acquisition of English; Fam_Hand = Familial handedness; RT_Var = RT variation

Figure 2. Interaction plot for response time data in Study 1, Radical Configuration Matching

4.2 STUDY 2 FOR RESEARCH QUESTION 2

Study 2, using the primed lexical decision task, investigated the research question, does the RH contribute preferentially to semantic processing in accessing meaning directly via orthography, bypassing phonology? It examined the RH's potential contribution to semantic processing with Chinese characters. Table 6 reports the descriptive information for the two outcome variables, accuracy and RT. GLMMs were again used to analyze participants' performance (see Table 6 for statistics). The two predictors, visual field and prime type, were analyzed separately for their main effects, and then together with their interaction term included.

Table 6. Descriptive data for accuracy and response time (for accurate responses) in Study 2

Visual Field Prime Type	Accuracy proportion Mean (SD) Range	Response Time (ms) Mean (SD) Range
Left (RH) Semantics	0.99 (.11) 0 – 1	377.16 (156.88) 104 – 1349
Left (RH) Semantics & Phonology	0.99 (.11) 0 – 1	364.51 (135.44) 128 – 936
Right (LH) Semantics	0.99 (.10) 0 – 1	362.82 (142.91) 39 – 1441
Right (LH) Semantics & Phonology	0.99 (.11) 0 – 1	388.62 (139.51) 92 – 893

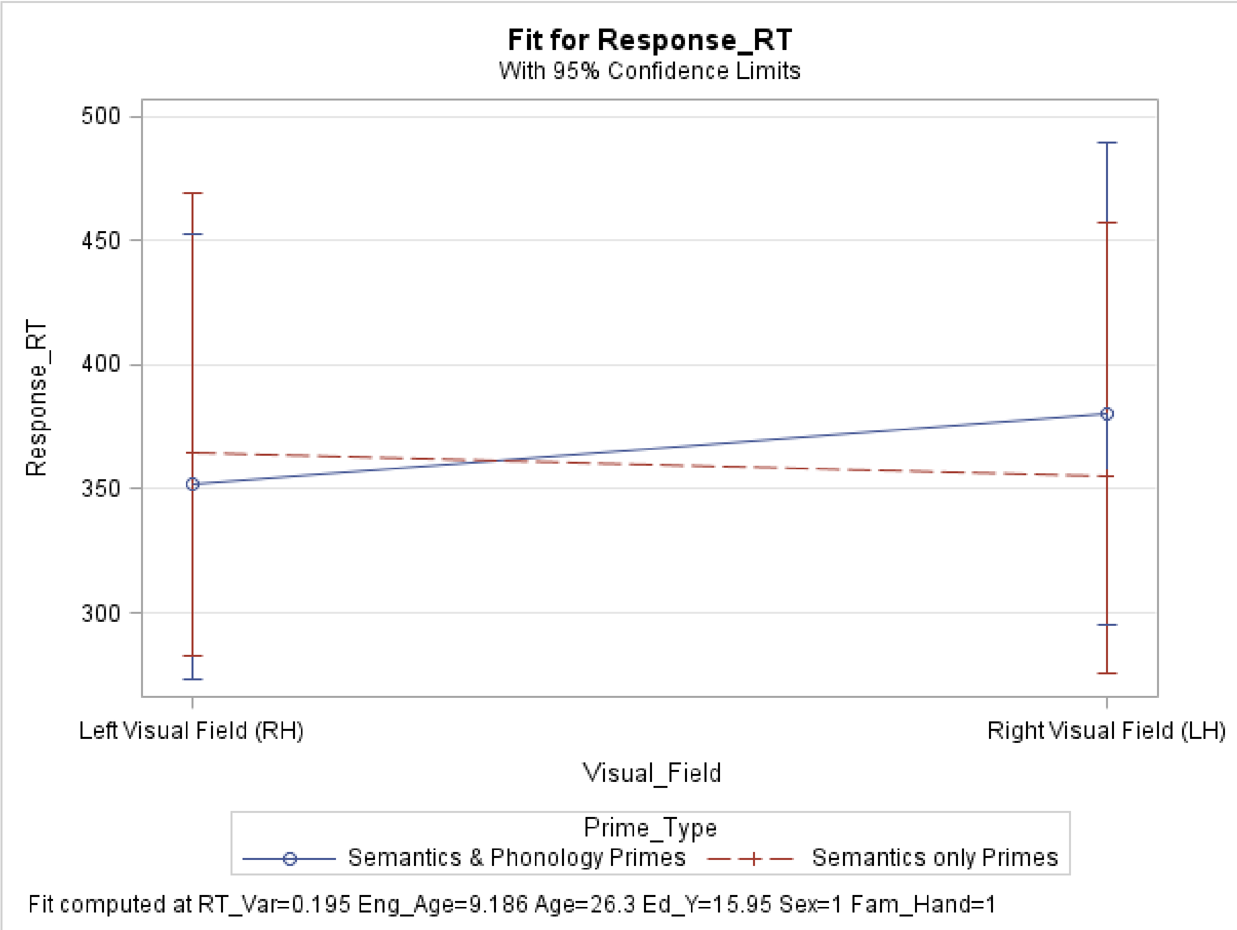
Note. RH = Right Hemisphere; LH = Left Hemisphere; ms = milliseconds

Table 7. Effects of visual field, prime type and their interaction

	Estimate	SE	t-value	df	*p*	CI
Accuracy						
Visual Field	.136	.522	.26	34	.797	[-.924, 1.195]
Prime Type	-.136	.522	-.26	34	.797	[-1.195, .924]
Visual Field × Prime Type	-.292	1.049	-.28	34	.783	[-2.423, 1.839]
Response Time						
Visual Field	.026	.014	-1.77	34	.086	[-.056, .004]
Prime Type	.02	.014	1.35	34	.185	[-.01, .049]
Visual Field × Prime Type	-.104	.029	-3.61	34	.001	[-.162, -.045]

For accuracy, there were no main effects of either predictor (visual field: $t_{(34)} = .26$, $p = .797$; prime type: $t_{(34)} = -.26$, $p = .797$). Nor was there a significant interaction between the two predictors (visual field * prime type: $t_{(34)} = -.28$, $p = .783$). None of the control variables showed significance throughout the analyses. In the final model of interaction, the statistics for these control variables were age: $t_{(28)} = -.84$, $p = .405$; age of acquisition of English: $t_{(28)} = 1.36$, $p = .185$; education: $t_{(28)} = .46$, $p = .651$; familial handedness: $t_{(28)} = 1.64$, $p = .112$; sex: $t_{(28)} = -.29$, $p = .777$; RT variation during the practice session: $t_{(28)} = -.97$, $p = .342$.

For RT, there were again no main effects for the two predictors (visual field: $t_{(34)} = -1.77$, $p = .086$; prime type: $t_{(34)} = 1.35$, $p = .185$), but there was a significant interaction (visual field * prime type: $t_{(34)} = -3.61$, $p = .001$). The fixed-effect estimates for this significant result were .026 for visual field, .0685 for prime type, and -.104 for visual field * prime type. Figure 3 plots this interaction, showing that with RVF/LH presentation, RT was longer for targets paired with the SP primes, which were pseudocharacters embedded with both phonological and semantic information, than with the S primes, which were pseudocharacters embedded with only semantic information. The post-hoc analysis of the RT outcome variable in the LVF/RH showed that there was no significant difference between the prime types ($t_{(34)} = -1.78$, $p = .085$). This result suggests that the two prime types had a similar effect on the RH's processing, as indicated by RT. There was, however, a significant RT difference between the prime types in the RVF/LH presentation condition ($t_{(34)} = 3.32$, $p = .002$). None of the demographic control variables showed significance throughout the RT analyses except for the RT variation. In the final model of interaction, the statistics for the demographic control variables were age: $t_{(28)} = .04$, $p = .968$; age of acquisition of English: $t_{(28)} = .55$, $p = .588$; education: $t_{(28)} = -.66$, $p = .517$; familial handedness: $t_{(28)} = -1.06$, $p = .3$; sex: $t_{(28)} = 1.31$, $p = .199$. The control variable, RT variation, was significant, when either one of the predictor variables, visual field ($t_{(28)} = -2.34$, $p = .027$) or prime type ($t_{(28)} = -2.33$, $p = .027$), was in the model of analysis. It was not significant in the final model of interaction ($t_{(28)} = -2.04$, $p = .0504$).



Note. Ed_Y = Education in years; Eng_Age = Age of acquisition of English; Fam_Hand = Familial handedness; RT_Var = RT variation

Figure 3. Interaction plot for response time data in Study 2, Lexical Decision

5.0 DISCUSSION

5.1 VISUAL-WORD-FORM ANALYSIS OF RADICAL CONFIGURATIONS

The first study was designed to investigate the RH's contribution to the visual-word-form analysis of radical configurations in Chinese script. Thus the focus of this study was on an early stage of the reading process at the perception-based level, before engaging and interacting with other linguistic-based cognitive processes, such as phonological and semantic activation processes (Huang & Wang, 1992). The neural basis of this level of analysis has been suggested to be in occipital and occipitotemporal regions (see discussion in Perfetti et al., 2013). Two hypotheses were proposed, aiming to disambiguate the relationship between the RH's ostensive processing preferences for radical configurations within Chinese characters and for low spatial frequencies.

The first hypothesis was that RH processing is preferentially involved in analyzing the radical configurations of Chinese characters. This hypothesis was derived from two sets of studies, one suggesting an association between RH processing and the global configuration of facial features, a T contour (e.g., Grill-Spector et al., 2004; Rossion et al., 2003) and the other suggesting an analogy between the global facial configuration and radical configurations of Chinese characters (e.g., Fu et al., 2012; Perfetti et al., 2013). However, the global configurations of radicals within Chinese characters are more complicated than the reliable T contour of facial features (e.g., Yeh et al., 1997, 1999), and the studies suggesting the association between the RH and radical configurations of Chinese characters did not directly examine the hypothetical association (e.g., Hsu et al., 2011; Nelson et al., 2009). The study conducted here, assessing radical configuration matching with the divided visual field paradigm, was designed to investigate the proposed association directly.

The second hypothesis was that this preferential processing at the visual word form level is independent of any RH contribution to processing low spatial frequencies. A low spatial frequency processing preference has often been attributed to the RH, with support from some previous studies (Peyrin et al., 2003; Piazza & Silver, 2014; Woodhead et al., 2011), but this attribution is controversial, without support from a number of other studies (Kitterle et al., 1990; Ossowski & Behrmann, 2015; Proverbio et al., 1997). Spatial frequency was integrated in the study as a predictor variable with two levels, low and normal.

Based on the hypotheses above, the expected outcomes included a main effect of visual field on the performance of radical configuration matching, in that performance (accuracy and RT) would be better for the target left-right configurations presented to the LVF/RH, where the visual analysis of radical configurations is lateralized, than for the same configurations presented to the RVF/LH. Also, there would be an interaction between visual field and spatial frequency on matching performance if the two hemispheres process radical configurations of Chinese script and spatial frequencies as two perceptual entities. The interaction would be demonstrated by a significantly different matching performance for stimuli presented to the LVF/RH, such that either those with low spatial frequency or with normal spatial frequency would be processed more accurately and/or faster.

5.1.1 RH, Radical Configurations, and Low Spatial Frequencies

Although accuracy was proposed as the primary outcome measure, accuracy was unexpectedly high, essentially at ceiling for all conditions. Thus there were no significant results in the accuracy analyses. The high accuracy might reflect that the task, radical configuration matching, was not difficult task for native Chinese speakers after being familiarized with it through practice. The DVF presentation, hence, did not deteriorate accuracy performance as proposed (e.g., Atchley et al., 1999).

As reported previously, there was a reliable interaction of visual field and spatial frequency on RT performance in radical configuration matching. The pattern of the interaction indicated that when the matching targets were presented in the RVF/LH, RTs were longer for those with normal spatial frequency (not blurred) than with low spatial frequency. By contrast, in the LVF/RH presentation condition, RT was significantly slower in the blurred (low spatial frequency) condition than for the normal spatial frequency items. This interaction suggests that the results are in part consistent with the second hypothesis. The hypothesis is supported by the finding that LVF/RH stimulus presentation generated slower RTs for the blurred target stimuli (low spatial frequency) than for the clear target stimuli (normal spatial frequency). In addition, this finding is contrary to the main effect that would be expected if the RH is better at processing low spatial frequencies. As such this result is in line with other studies leading to the conclusion that the relationship between the RH and low spatial frequency processing is equivocal. For example, in Section 2.1.5, the study of Volberg (2014) was introduced to illustrate the RH's advantage in detecting a path contour without the involvement of low spatial frequency. In addition, Dale and Arnnell (2014) reported that the individual differences in categorizing stimuli with reference to their global or local features were not affected by exposure to stimuli containing either low or high spatial frequencies. Their findings resonate with the overall pattern of results in the current study and are consistent with the argument that radical configurations and spatial frequencies can be processed as independent perceptual entities. Thus, the RH's involvement in processing Chinese characters can be attributed to the analysis of radical configurations, independent of spatial frequency characteristics.

5.1.2 RH, Radical Configurations, and Exposure Effects

The part of the current study's results that is inconsistent with the primary hypotheses is the nonsignificant main effect of visual field, which goes against the prediction of preferential RH processing of radical configurations. Two factors could plausibly contribute to the lack of the proposed main effect. First, the hypothesized main effect was based on the conventional wisdom regarding the RH's dominance for low spatial frequency processing. As just reported, however, the current findings augment the literature contrary to that notion. Thus, the lack of main effect could be owing to the inclusion of low spatial frequencies in the study. In the normal spatial frequency condition, RH stimulus presentation did demonstrate faster processing than LH presentation for the task of radical configuration matching.

The other reason for the lack of a visual field effect could be due to the choice to use only left-right radical configuration as experimental target items. The matching and mismatching experimental trials in this study were either left-right or top-bottom/wrapped, both paired with left-right targets. There were (no matched pairs of top-bottom items and) no mismatches such as top-bottom vs. wrapped. Using the same radical configuration matching task with left-right and top-bottom configurations balanced in matching and mismatching pairs, Yu and Cao (1992) found the RTs were the fastest with the left-right matching pairs and the slowest with the top-bottom matching pairs, with the mismatching pairs in the middle. Faster RTs for characters with the left-right configuration than those with the top-bottom configuration were also observed in other studies. For example, when naming the individual stand-alone radicals within a character by their orthographic writing sequence (left then right, top then bottom), RTs were faster for radicals in the left-right configuration than in the top-bottom configuration (Yu, Feng, Cao, & Li, 1990). In addition, when deciding if a target radical was embedded in the following character, RTs were faster in decisions about characters with the left-right configuration than those with the top-bottom configuration (M.-Y. Wang, 2002).

The consistent processing superiority of the left-right configuration possibly results from the high prevalence of the left-right configuration in natural language processing, with more than 80% of Chinese characters having this configuration. The effect of word frequency on hemispheric processing contributions has also been observed in lexical decisions with English stimuli when phonological decoding of the alphabetical orthography is required through addressed and assembled routes (Seidenberg, 1985). For example, Voyer (2003) found accuracy to decrease for low frequency words presented to the LVF/RH. Rutherford (2014) reported that when lexical decision involved only high frequency words, higher accuracy was obtained for stimuli presented to the LVF/RH. When both high and low frequency words were involved, higher accuracy on low frequency words and faster RTs on high frequency words were found in the RVF/LH presentation condition. A connecting analogy regarding the hemispheric contributions observed from the two tasks, radical configuration matching and lexical decision, lies in shifting labor to the LH when more detail-oriented processing is required. For the configuration matching task, the relatively high exposure to the left-right configuration in natural language may affect the processing of the stimuli so that one can devote attentional resources to the local features of the composite stimuli (characters or letters). On the other hand, the low frequency words in the lexical decision task may require not only the addressed decoding route but also the assembled decoding strategy for grapheme-phoneme transcription. Another example of the RH's contribution to non-detail-oriented or fine-tuned processing is its specialty in the coarse semantic coding that it tends to maintain the activation of a semantic field with broad and distant semantic features (see discussion in Jung-Beeman, 2005).

In addition to effects based on prevalence in natural language, exposure within an experimental context may also influence hemispheric preferential processing. For example, Förster (2009) investigated the frequency of exposure to foreign script and the perception of global configurations by varying the amount of exposure that his non-Hebrew speaking participants received to Hebrew letters. Then the participants were asked to decide if a target letter (e.g., נ) composed of small letters (e.g., ג) looked more like one of two sample letters, e.g., a letter, נ, made of small ןs or a letter, ב, made of small גs. He found that when they had fewer or no exposures to the stimuli, participants tended to choose a match based on the global configuration of the letters. In addition, overall, the higher the frequency of exposure, the greater the tendency to match the letters by their local features. Linking the aspects of natural language exposure and experimental context exposure together, if the RH is specialized for processing global configurations and an increased exposure frequency is prone to diminish the processing of global configurations, it is possible that the hypothesized LVF/RH effect in the current study was washed out by the participants' exposure to the frequent left-right configurations utilized in the experiment.

Thus, higher exposure to one specific configuration in the context of natural language acquisition and higher exposure in an experimental setting can both possibly modulate the hemispheric contribution to processing the configurations among radicals. In the current study, both the exposure to more characters with the left-right configuration than to ones with other configurations and the prevalence of the left-right configuration in Chinese script could plausibly explain the lack of the predicted visual field effect. It is worth noting that such different aspects of exposure may modulate hemispheric contributions differently. Future studies will be required to investigate such potential differences. One direction for future research is to design an experiment including other types of configurations, for example, top-bottom and wrapped, and manipulate the exposure frequency to investigate the effects of exposure within an experimental setting on the RH's hypothesized preference for processing radical configurations. It will also be essential to design a study including different types of configurations with a balanced frequency of exposure for examining the effect of degree of prevalence among types of radical configurations in Chinese script on the RH's hypothesized preferential processing. In addition, taking the potential effect of exposure frequency into consideration, when investigating the controversial relationship between RH and low spatial frequencies, it will be important to use amount of exposure as a predictor to obtain new evidence about the unsettled, and likely complex, relationship.

5.1.3 LH, Radical Configurations, and Phonological Processing

Shifting the focus of this discussion briefly from the right side of the brain to the left, LH stimulus presentation yielded slower processing when the target stimuli were clear (normal spatial frequency) than when they were blurred (with low spatial frequency). This finding could reflect the processing of phonological information embedded in the phonetic radicals of the phonograms (typically left-right configurations), processing which is inevitably sublexical (Lee et al., 2006; X. Zhou & Marslen-Wilson, 1999). Results of both a primed naming study (X. Zhou & Marslen-Wilson, 1999) and an ERP study assessing the N400 response (Lee et al., 2006) suggest automatic sublexical processing of the radicals' linguistic information, both phonological and semantic, if the radicals can stand alone as characters. Such sublexical processing is activated even when that information is different from or irrelevant to the information conveyed by the overall characters.

The findings from the LH presentation condition could reflect a result analogous to the famous Stroop effect (Stroop, 1935), in which naming the ink color of a color word (e.g., "red") takes longer when the ink color does not match the color word itself (e.g., the word "red" printed in blue ink) than when the ink color matches the color word (e.g. the word "red" printed in red ink). The RT interference of the Stroop effect is due to interference from the habitual response to a word stimulus (reading the word itself) when an atypical response, in this case one that is perceptually-based, is required instead (naming the ink color) (Stroop, 1935; van Maanen, van Rijn, & Borst, 2009). In the current study, the unavoidable activation of phonological information that was not required for the more perceptually-based task of radical configuration matching, might produce a Stroop-effect-like interference. One example of the potential interference of the inevitable activation of sublexical phonological information is provided by Yu et al. (1990). When the authors asked their participants to name the configurations instead of the radicals of a compound character, for example "left" for a character with left-right configuration, and "top" for top-down configuration, there was no difference in RT performance in naming the two configurations, compared with the faster RT on naming the radicals within left-right than top-down configurations. The disappearance of the processing superiority of the left-right configuration could be attributed to the task of naming configurations, instead of radicals, interfering with the automatically activated sublexical phonological information. The suggested influence of the sublexical phonological information on processing the radical configuration is intriguingly analogous to the Stroop effect. It is also possible that interference costs occurred because the configuration matching task required a nonhabitual, metalinguistic processing of radical configurations, forced to be processed explicitly against what is habitual in natural language processing.

Future studies will be required to investigate this potential interference or inhibition from sublexical processes, such as inevitable phonological activation, on a metalinguistic process such as radical configuration matching, particularly when the experiment requires an atypical, metalinguististic response instead of habitual, natural processing. This potential interference is another reason why an experiment will be important that includes other types of configurations than left-right. As discussed previously, most left-right configured Chinese characters are phonograms which contain many regular phonetic radicals. By introducing other types of radical configurations which are less frequent in occurrence and likely contain more irregular or even no phonetic radicals, the relationships between sublexical phonological processing and metalinguistic configuration processing can be further scrutinized.

5.1.4 Strengths, Limitations, and Future Directions

The major strength of this study lies in testing the validity of an interconnected set of assumptions concerning the presumed nature of an assumed RH preference for processing radical configurations in Chinese script. One aspect of the line of argument is that a RH advantage for radical configuration processing has been presumed to reflect a broader RH advantage for processing low spatial frequency stimuli. As addressed previously, the line of logic and evidence behind this presumption is theoretically controversial. This study directly challenged this presumption, utilizing a design in which low spatial frequency processing could be examined as an independent contributor to the experimental task of radical configuration matching. The results were contrary to the conventional wisdom, indicating that the two processes are independent. This work introduces a path which leads to future studies examining the relationship between the RH and Chinese script processing through radical configurations, without taking low spatial frequencies for granted as a mediator. Another strength of the current study lies in the proposal of several possible exposure/frequency-based interpretations for the lack of hypothesized main effect of visual field on radical configuration matching. This line of theorizing points the way toward investigating a new set of potential mediators on the complex and likely dynamic nature of hemispheric contributions to radical configuration processing.

This new line of theorizing emerged from a limitation of this study, specifically, focusing too exclusively on the left-right configuration and failing to consider relative exposure frequency within the experimental context as a modulating variable. There are several other limitations in terms of the design, as well. One of them is that the study method, using DVF presentation, can only grossly imply the underlying hemispheric contributions. It will be crucial to have other neural imaging modalities, such as fMRI, to elaborate on the nature of the current findings. In addition, it will be intriguing to examine neuropsychological findings from patient groups, such as RH damaged group vs. LH damaged group, to evaluate the correspondence between results.

5.2 DIRECT ACCESS TO SEMANTICS VIA ORTHOGRAPHY BYPASSING PHONOLOGY

The second study aimed to examine an hypothesized RH processing route directly from orthography to semantics, without any scaffolding of phonology. A direct orthography-semantics access was implied in one of the later modifications of the Lexical Constituency Model, that stipulates that the timing of phonological activation could be different in alphabetic languages like English and ideographic languages like Chinese, depending on the different interactions among phonology, orthography, and semantics in each writing system (Perfetti et al., 2013, 2005). Irrelevant to the ideographic/logographic characteristic, which is found in fewer than 20% of contemporary Chinese characters (DeFrancis, 1989), Perfetti and Tan (1999) pointed out a distinct feature of Chinese script that when one radical does not stand alone as a simple character (aka a non-stand-alone radical), it has only a semantic representation; thus a direct orthography-semantics route must exist. What has been overlooked thus far regarding this direct access from orthography to semantics is its cerebral hemispheric foundations.

The current project proposed that the foundation of this direct orthography-semantics access is lateralized to the RH. The basis of this hypothesis was developed from several sets of findings. First, the RH is more involved than the LH in processing characters when experimental tasks do not require phonological processing (e.g., Dong et al., 2005; M.-J. Yang & Cheng, 1999). Second, neuroimaging studies consistently show that the RH is involved while viewing pseudocharacters for lexical-semantic processing as long as there are existing radicals embedded (e.g., Hsu et al., 2011; J. Yang et al., 2012). Third, Chinese script can provide access to semantics though orthography without decoding phonology (e.g., Lee et al., 2006; X. Zhou &

Marslen-Wilson, 1999). In contrast, the LH demonstrates a specialty in phonological processing on linguistically-related tasks (e.g., Brem et al., 2010; Seghier & Price, 2011; Wu et al., 2012). Also, an ERP study (Lin et al., 2011) found that the LH was not engaged in processing pseudocharacters when they contained the non-stand-alone radicals but was involved when the pseudocharacters contained stand-alone radicals that provided phonological information. Finally, based on the converging findings, plus the RH's potential access to semantics involving various regions including its frontal areas (e.g., Jung-Beeman, 2005; Y. Yang et al., 2015), the proposed right lateralization represents a process beyond the conventional visual-word-form analysis of Chinese characters (e.g., Perfetti et al., 2013).

According to the literature review, in the event that such a route exists, three hypothetical outcomes were proposed. The first two were developed regarding the RH's preferential processing, and the third one was focused on LH processing. For stimuli presented to the LVF/RH, one possibility was that S primes, which were pseudo-characters composed of a Korean symbol and a non-stand-alone radical containing semantic information, would facilitate the lexical decision for a subsequent target character which is semantically associated to the prime. Alternatively, the second possibility suggested that both S primes and SP primes, which were made of a Korean symbol and a stand-alone radical containing both semantic and phonological information, when presented in the LVF/RH would facilitate the lexical decision. For the LH, it was suggested that SP primes but not S primes would facilitate the lexical decision when the stimuli were presented in the RVF/LH.

5.2.1 RH and Direct Orthography-Semantics Route Regardless of Phonology

No significant outcomes were found for the accuracy measure. Again, the lack of significant results can be attributed to the unexpectedly, extremely high performance in all conditions. Furthermore, the extremely high accuracy contributed to the nonsignificant intercept in both the empty model and the final model of the interaction, indicating that participants coherently achieved such high accuracy in the experiment. This result may reflect the fact that for the participants in this study who have at least a high school education, it was easy to process the lexical decision, especially when the target characters did not go beyond middle school level and after substantial amounts of practice.

The RT results thus became the primary outcome measure. In terms of the RH's processing preference, the results are in favor of the second alternative. Facilitation is evident in slower lexical decision RTs on target characters preceded by SP primes presented to the RVF/LH than to the LVF/RH, and by the finding that there is no difference in RTs between the two prime types in the LVF/RH presentation condition. These findings indicate that the RH can utilize the semantic information extracted from both the non-stand-alone radicals embedded in S primes, which contain only semantic information, and the stand-alone radicals embedded in SP primes, which contain both semantic and phonological information. Thus it appears that the hypothesized orthography-semantic route can indeed be accessed in the RH, regardless of the presence of phonological information. It may be that the RH is insensitive to the sublexical phonological information which has been proposed to be activated automatically (Lee et al., 2006). The current result is also in accordance with an fMRI study (S. Chan et al., 2009) and an ERP study (Lin et al., 2011) in which the RH was involved in processing pseudocharacters which contained legal radicals, whether or not the radicals could stand alone.

It will be essential for future studies to utilize neuroimaging technologies, such as fMRI or MEG, to investigate whether activated regions during the primed lexical decision task correspond to the hypothesized orthography-to-semantics route. This route radiates beyond the cerebral visual processing areas and should attain frontal areas, indicating access to semantic processing. It will also be intriguing to examine the modulators of accessibility of the hypothesized direct orthography-to-semantics route. For instance, future studies can investigate whether the route is influenced by knowledge of Chinese script by comparing the performance between participants across different levels of education, and whether the degree of accessibility is different between Chinese native speakers and Chinese second language learners.

5.2.2 LH and Weak Semantic Association

As for the LH, the result is different from the hypothetical outcome, in that with LH stimulus presentation, targets preceded by SP primes were actually processed more slowly than the targets preceded by S primes. This finding could be explained by the fact that the target characters selected for this study have only a weak/coarse semantic association with the primes. The weak semantic association was explicitly incorporated in this study because the RH's preferential processing was the major focus of the research question, and the RH has demonstrated the tendency to respond to words sharing distantly related semantic features but not necessarily those from the same semantic category (Deacon et al., 2004), indicating a coarse semantic coding mechanism (Jung-Beeman, 2005).

The weak association between primes and targets was the consequence of the method used to select the target characters, including a free association task and expert judgment by a Chinese linguist. In addition, there was linguistic control that the target characters could not form frequent words with the radicals when they stand alone as characters. Therefore, the phonological information from the stand-alone radicals might barely be able to mediate the semantic association for the target characters. Given the weak semantic association between primes and targets, the literature suggesting the LH's preferential processing in strong semantic coding (Bouaffre & Faïta-Ainseba, 2007; Reilly et al., 2015; Sass, Krach, Sachs, & Kircher, 2009), and the rampant number of homophones among Chinese characters, the embedded weak semantic and irrelevant phonological information in SP primes might not satisfy the conditions required to facilitate the LH's process of lexical decision for the subsequent target characters.

5.2.3 Strength, Limitations, and Future Directions

One major strength of this study lies in its innovative question, which explored a novel potential aspect of RH processing for Chinese script. Specifically, this study hypothesized a RH role for accessing semantics via orthography directly, regardless of the involvement of phonology. The results are consistent with this hypothesis, and push forward an alternative theoretical framework of a linguistic RH contribution to processing Chinese characters, outside of the conventional emphasis solely on the perceptually-based visual-word-form analysis. Another strength of this study was exploiting the unique features of Chinese script to provide a new insight into the RH's contribution to language processing which cannot be addressed with alphabetic language stimuli.

In terms of the limitations, it will be important in the future to investigate whether the direct orthography-semantics route can be accessed only via processing weak semantic associations. After all, the theory of RH's coarse semantic coding has been primarily established through alphabetic languages. Although there are studies showing the RH's involvement in processing Chinese metaphors (e.g., Ahrens et al., 2007) studies at the lexical level are in need to scrutinize the hemispheric lateralization of coarse semantic coding in Chinese. The previously discussed limitations of the study method, DVF, and the study population are imposed on this study, too. It will be unequivocally essential to adopt neuroimaging modalities and to extend to patient groups with unilateral cerebral damage in future studies, to further examine the nature and characteristics of the proposed direct route from orthography to semantics in the RH. Furthermore, future studies can also investigate a hypothetical interaction between the visual-word-form analysis of the radical configurations and the access from orthography to semantics when the majority of the left-right configured Chinese characters are phonograms with the semantic radicals embedded on the left side and the top-bottom configured characters contain less consistent positions of their semantic radicals.

APPENDIX A - Instructions

A.1 Practice session for Study 1

A.1.1.1 For this part of practice, you'll decide if a character is in a Left-Right configuration. Make your decision by pressing the YES or the NO keys. When you see a number, press YES if it's an odd number, and press NO if it's an even one. Press the SPACE bar to start the practice.

A.1.1.2 For this part of practice, you'll decide if a character is in a Top-Bottom configuration. Make your decision by pressing the YES or the NO keys. When you see a number, press YES if it's an odd number, and press NO if it's an even one. Press the SPACE bar to start the practice.

A.1.1.3 For this part of practice, you'll decide if a character is in a Wrapped configuration. Make your decision by pressing the YES or the NO keys. When you see a number, press YES if it's an odd number, and press NO if it's an even one. Press the SPACE bar to start the practice.

A.1.2 For this part of practice, you'll match the configuration of two characters. If the two characters contain the same configuration, press the YES key. If the two characters contain different configurations, press the NO key. Keep your eyes on the cross (+) all the time. Press the SPACE bar to start the practice.

A.1.3 For this part of practice, you'll match the configuration of two characters. If the two characters contain the same configuration, press the YES button. If the two characters contain different configurations, press the NO button. When you see a number, press YES if it is an odd number, press NO if it is an even number. Keep your eyes on the cross (+) all the time. Press the SPACE bar to start the practice.

A.2 Study 1 instructions

For this experiment, you'll match the configuration of two characters. If the two characters contain the same configuration, press the YES button. If the two characters contain different configurations, press the NO button. Keep your eyes on the cross (+) all the time. Press the SPACE bar to start the practice.

A.3 Practice session for Study 2

A.3.1 For this part of practice, you'll decide if a character is a REAL character or NOT. Keep your eyes on the cross (+) at the center. Make your decision by pressing the YES or the NO buttons. When you see a number, press YES if it's an odd number, and press NO if it's an even one. Press the SPACE bar to start the practice.

A.3.2 For this part of practice, you'll decide if the 2nd image is a REAL character or NOT. Keep your eyes on the cross (+) at the center. Make your decision on the 2nd image. Press YES if the 2nd image is a REAL character. Press NO if the 2nd image is NOT a real one. When you see a number, press YES if it is an odd number, and press NO if it is an even number. Press the SPACE bar to start the practice.

A.3.3 For this part of practice, you'll decide if the 2nd image is a REAL character or NOT. Keep your eyes on the cross (+) at the center. Make your decision on the 2nd image. Press YES if the 2nd image is a REAL character. Press NO if the 2nd image is NOT a real one. When you see a number, press YES if it is an odd number, press NO if it is an even number. Press the SPACE bar to start the practice.

A.4 Study 2 instructions

For this experiment, you'll decide if the 2nd image is a REAL character or NOT. Keep your eyes on the cross (+) at the center. Make your decision on the 2nd image. Press YES if the 2nd image is a REAL character. Press NO if the 2nd image is NOT a real one. Press the SPACE bar to start the practice.

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