4-17-2020 2:00 PM

The Impact of Text Orientation on Form Effects with Chinese, Japanese and English readers

Huilan Yang
The University of Western Ontario

Supervisor
Dr. Stephen J. Lupker
The University of Western Ontario

Graduate Program in Psychology
A thesis submitted in partial fulfillment of the requirements for the degree in Doctor of Philosophy

Recommended Citation

Yang, Huilan, "The Impact of Text Orientation on Form Effects with Chinese, Japanese and English readers" (2020). *Electronic Thesis and Dissertation Repository*. 6925.
https://ir.lib.uwo.ca/etd/6925

Abstract

Does visuospatial orientation influence form priming effects in parallel ways in Chinese and English? Given the differences in how orthographic symbols are presented in Chinese versus English, one might expect to find some differences in early word recognition processes and, hence, in the nature of form priming effects. According to perceptual learning accounts, form priming effects (i.e., “form” priming effects) should be influenced by text orientation (Dehaene, Cohen, Sigman, & Vinckier, 2005; Grainger & Holcomb, 2009). In contrast, Witzel, Qiao, and Forster’s (2011) abstract letter unit account proposes that the mechanism responsible for such effect acts at a totally abstract orthographic level (i.e., the visuospatial orientation is irrelevant to the nature of the relevant orthographic code). One goal of the present research was to determine whether or not one of these accounts could explain form priming effects in both languges.

Chapter 2 (Yang, Chen, Spinelli & Lupker, 2019) expanded the debate between these positions beyond alphabetic scripts and the syllabic Kana script used by Witzel et al. (2011) to a logographic script (Chinese). I report four experiments with Chinese participants in this chapter. The experiments showed masked form priming effects with targets in four different orientations (left-to-right, top-to-bottom, right-to-left, and bottom-to-top), supporting Witzel et al.’s account.

Chapter 3 (Yang, Hino, Chen, Yoshihara, Nakayama, Xue, & Lupker, in press) provided an evaluation of whether the backward priming effect obtained in Experiment 2.3 (i.e., backward primes and forward targets) is truly an orthographic effect or whether it may be either morphologically/meaning- or syllabically/phonologically-based. Five experiments, two involving phonologically-related primes and three involving meaning-related primes, produced no evidence that either of those factors contributed to the backward priming effect, implying that it truly is an orthographic effect.

In Chapter 4 (Yang & Lupker, 2019), I examined whether text rotation to different degrees (e.g., 0°, 90°, and 180° rotations) modulated transposed-letter (TL) priming effects in two experiments with English participants. The sizes of the priming effects were similar for horizontal 0°, 90° rotated and 180° rotated words providing further support for abstract letter unit accounts of orthographic coding.

These results support abstract letter/character unit accounts of form priming effects while failing to support perceptual learning accounts. Further, these results also indicate a language difference in that Chinese readers have more flexible (i.e., less precise) letter position coding than English readers, a fact that poses an interesting new challenge to existing orthographic coding theories.

Keywords

Repetition priming, Transposition priming, Orthographic, Phonological, Morphological.

References

Dehaene, S., Cohen, L., Sigman, M., & Vinckier, F. (2005). The neural code for written words: A proposal. *Trends in Cognitive Sciences, 9*(7), 335–341. https://doi.org/10.1016/j.tics.2005.05.004

Grainger, J., & Holcomb, P. (2007). Neural Constraints on a Functional Architecture for Word Recognition. *L'anne´e Psychologique*, *107*, 623– 658. https://doi.org/10.1093/acprof:oso/9780195300369.003.0001

Witzel, N., Qiao, X., & Forster, K. (2011). Transposed letter priming with horizontal and vertical text in Japanese and English readers. *Journal of Experimental Psychology: Human Perception and Performance*, *37*(3), 914–920. https://doi.org/10.1037/a0022194

Yang, H., Chen, J., Spinelli, G. & Lupker, S. J. (2019). The Impact of Text Orientation on Transposed Character Priming Effects in Four-Character Chinese Words. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *45*(8), 1511–1526. https://doi: 10.1037/xlm0000655

Yang, H., Hino, Y., Chen, J., Yoshiharo, M., Nakayama, M., Xue, J. & Lupker, S. J. (2020). The Origins of Backward Priming Effects in Logographic Scripts for Four-Character Words. *Journal of Memory and Language 113*, 104107.

Yang, H. & Lupker, S. J. (2019). Does Letter Rotation Decrease Transposed Letter Priming Effects? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *45*(12), 2309–2318. https://doi.org/10.1037/xlm0000697

Summary for Lay Audience

Does text orientation influence masked form priming effects, for example, identity priming effects which arise when the prime and target are identical or transposed character (TC) priming effects which arise when the prime involves a transposition of the target's letters such as with huose priming the target word HOUSE? According to perceptual learning accounts, the nature of such effects should be influenced by text orientation (Dehaene, Cohen, Sigman, & Vinckier, 2005; Grainger & Holcomb, 2009). In contrast, Witzel, Qiao, and Forster's (2011) abstract letter unit account argues that the mechanism responsible for such effects acts at a totally abstract orthographic level (i.e., text orientation does not influence repetition and TC priming effects).

Chapter 2 (Yang, Chen, Spinelli & Lupker, 2019) expanded this debate beyond alphabetic scripts and the syllabic Kana script used by Witzel et al. (2011) to a logographic script (Chinese). Four experiments with Chinese participants showed masked repetition and TC priming effects with four different orientations of the target word (left-to-right, top-to-bottom, right-to-left, and bottom-to-top, even though the latter two conditions are unfamiliar).

Chapter 3 provided an evaluation of whether the priming effect in Experiment 2.3 in which the primes were the targets written backwards (e.g., in the Roman alphabet ecaf priming FACE) is truly an orthographic effect or whether it may be either morphologically/meaning- or syllabically/phonologically-based. Five experiments, two involving phonologically-related primes and three involving meaning-related primes, produced no evidence that either of those factors contributed to the backward priming effect, implying that it truly is an orthographic effect.

In Chapter 4 (Yang & Lupker, 2019), I examined whether text rotation to different degrees (e.g., 0°, 90°, and 180° rotations) modulated transposed-letter (TL) priming effects in two experiments with English participants. Results revealed the sizes of the TL priming effects were similar for horizontal 0°, 90° rotated and 180° rotated words providing further support for abstract letter unit accounts of orthographic coding.

Co-Authorship Statement

Chapter 2-4 of this dissertation represent three manuscripts that have been accepted for publication in major, peer-reviewed journals. All were co-authored with my supervisor, Dr. Stephen J. Lupker, with two of them also involving other collaborators. I am this first author on all of them. Dr. Lupker supervised my research and helped with the editing all of these publications as well as the editing of this dissertation.

Acknowledgments

Firstly, I am extremely grateful to my supervisor Dr. Stephen Lupker. He has been a source of incredible support and encouragement throughout my graduate career. I thank my supervisor for being patient and helpful even in those times when I proposed some “strange” experiments, to thank him for giving me a lot of opportunities to try and to learn from failures. As a famous saying goes, “you will never know if you never try”. His rigorous attitude and enthusiasm for science will always guide me.

I wish to acknowledge the helpful comments from my advisory committee, Dr. Debra Jared and Dr. Lisa Archibald. Their input has helped me to improve the quality of this research. I feel that I have been particularly lucky to have had Dr. Jared on my advisory committee, as she has given me a considerable amount of insightful advice on writing and on how to extend my work in further studies. She has also given me some good advice on professional development.

I would also like to thank my external collaborators who have contributed to the development of the papers contained in my PhD thesis, Yasushi Hino, Jingjun Chen, Masahiro Yoshihara, Mariko Nakayama and Junyi Xue. Without their help, it would have been impossible to get both the Japanese data and some of the Chinese data. I would also like to thank them for their pertinent advice and intellectual contributions to my thesis.

I also wish to thank my family for supporting me while I pursued the academic career that I love so much and encouraging me when things were not always going well. Their love and care mean more than words can express. I also want to express my appreciation to my family for keeping in touch with me regardless of the 12 hour time difference between China and Canada. Thanks also to the WeChat company for providing a free media that let us video chat every day.

Next, I would also like to thank Jeffrey Reid, Giacomo Spinelli, Alexander Taikh, Zian Chi, Lingling Li, Hamad Al-Azary, Xuan Pan, Mark McPhedran, Jason Perry and James Boylan who have been my closest friends and labmates during my PhD career. They taught me how to design experiments scientifically and how to effectively analyze the research data. We have come to have a lot in common, for example, our popular birthday wishes to one another are usually to get a *p* value which is less than 0.05. And I also want to thank them for their support and encouragement, as it's been a challenge for me to finish my PhD in a totally new environment, and their help has played an important role in me having a happy and meaningful PhD career.

Finally, I wish to thanks to all the comprehensive exam committee (Dr. Ken McRae, Dr. Paul Minda and Dr. Debra Jared) for their helpful comments throughout the years, comments that have been great contributions to my research projects.

Table of Contents

List of Tables

List of Figures

List of Appendices

Chapter 1

1 General Introduction

The “orthographic code” is the term used to refer to the mental representation of letter identity and letter position information in the word being read. It is important that the orthographic code correctly represent position information so that words like “teach” and “cheat”, which contain the same letters but in different order and, therefore, have different meanings, can be distinguished. Yet, even though letter position coding is important, our reading system still shows some flexibility. Consider the following text: “It deosn't mttaer in waht oredr the ltteers in a wrod are”. This example shows that the system is tolerant of letter transpositions even though it needs to get letter order right in the end. My research seeks to understand how the orthographic coding system both successfully reads text composed of transposed letter (TL) stimuli while at the same time allowing readers to distinguish between anagrams like teach and cheat.

The TL effects currently in the literature can be explained by most orthographic coding models (e.g., Davis, 2010; Gómez, Ratcliff, & Perea, 2008; Grainger & Van Heuven, 2003). That is, these models can accommodate the idea that letter position coding is somewhat imprecise, although they also predict that there are limits to this imprecision. However, one issue that these models do not concern themselves with is the question of the language differences in orthographic coding. All of these models have been based on results from experiments in alphabetic languages (e.g., English, French, Dutch) while tacitly assuming that the principles contained in the models would apply to languages involving other types of scripts (e.g., logographic languages like Chinese). Research conducted using nonalphabetic languages is, therefore, also going to be required as theorists attempt to broaden the scope of their models. Indeed, the amount of such research is increasing rapidly and is now sufficient to allow a contrast with the results obtained in alphabetic languages. Therefore, this literature is now providing a further ground for testing those orthographic coding models.

The present research focuses on three different languages, Chinese, Japanese and English. Chinese is a logographic language, and it is the oldest currently existing writing system in the world. Chinese is used by a huge population in East Asia, and has historically spread throughout the area of the Sinosphere. Hence, Chinese is now one of the dominant languages in the world. Chinese characters have also been adopted for use in other languages. Japanese Kanji characters are mainly borrowed from Chinese, and Chinese characters also occasionally appear in Korean Hanja script and Vietnamese. Logographic languages like Chinese and logographic scripts like Japanese Kanji present the largest contrast to alphabetic script languages like English.

A brief overview of Chinese would be useful in order to explain the difference between Chinese and English. Chinese has been regarded as a meaning-based language rather than a phonology-based language (Baron & Strawson, 1976; Wang, 1973). Chinese words vary from one to six characters, with two-character words accounting for the largest proportion (65%) of words (Huang & Liu, 1978). Each two-character word will have a whole word meaning, but each character also can have an independent meaning. Two character words are similar to English compound words, but English compound words represent only a small proportion of English words (Chen & Tzeng, 1992).

In terms of orthography, single Chinese characters are usually treated as the basic orthographic unit like English letters, so that principles generated from English letter recognition and its impact on word recognition should apply to Chinese character processing. Most Chinese character do, however, usually consists of smaller “radical” components (214 radicals in total). A radical is a simple character which has its own meaning or phonology. Most Chinese characters have two radicals. For instance, the character 吓 (/xia4/,” scare”) involves the radical 口 (/kou3/,”mouth”) on the left and the radical 下 (/xia4/,” underneath”) on the right. These two radicals vividly describe the actions often arising when people are scared, that is, they often open their mouths and hide underneath the covers. Two radical characters comprise the majority of Chinese characters. Radicals usually contribute semantic or phonetic information to the whole word, such as in the last example, the radical 下(/xia4//,” scare”) has the same sound as the character 吓 (/xia4/,” scare”).

For a number of reasons, most of the Chinese words used in the present experiments are four-character words. Most four-character Chinese words are known as *Chéngyŭ* words, which are words that mainly originated in Chinese ancient literature. The meaning of a *Chéngyǔ* word often surpasses the individual meanings of each single character and those words also often link to Chinese traditional stories, myths or historical facts, so that *Chéngyǔ* do not necessarily follow the grammatical and syntatic rules of modern Chinese. *Chéngyǔ* words are also impossible to understand without some background knowledge. For example, 破釜沉舟 ("break the woks, sink the boats") is derived from a historical event, in which General Xiang Yu asked his army to destroy all the kitchenware and boats after entering the enemy's territory through a river in order to prevent his soldiers from considering retreating. Ultimately, he won the battle due to this non-retreat strategy. This word has a similar meaning to the English phrase "point of no return".

Some *Chéngyǔ* also involve metaphorical ideas, for instance, 一手遮天 ("cover the sky with one hand") represents the idea that powerful people can hoodwink the public. Although most of the four-character Chinese words involve very complex sets of semantic information, there are also some four-character Chinese words that only represent simple semantic information. For example, 不好意思 only represents a simple meaning, “sorry”. Nowadays, four-character Chinese words are often regarded as the embodiment of Chinese culture in that they can contain old stories, moral concepts, metaphors, and admonishments from Chinese Ancestors but, importantly, they still play a central role in modern Chinese. Nonetheless, although there are over 11,000 four-character Chinese words list in *SUBTLEX-CH* database (Cai & Brysbaert, 2010), the relevant literature on four-character Chinese words is sparce (Gu & Li, 2015). However, as will be explained below when considering the manipulations used in my experiments, due to their length, they provide the optimal stimuli for use in these experiments.

What is also important to note is that although Chinese is a logographic, as opposed to an alphabetic, language, it also can be classified as a morphosyllabic language (Mattingly, 1992). Thus, the possibility exists that effects involving characters in Chinese may not be purely orthographic, but may also be morphemic and/or syllabic. In the present experiments, one of the main manipulations will involve a transposition of Chinese characters with the result being a transposed character (TC) effect. In alphabetic languages, the parallel manipulation (a TL manipulation) is an orthographic manipulation. In Chinese, it may not be. That is, when Chinese characters are transposed, they are, typically, able to provide appropriate morphemic and syllabic information even though that information now appears in incorrect positions. For example, 突如其来(/tū rú qí lái/, suddenly) is a Chinese four-character word that, when the middle characters are transposed 突其如来(/tū qí rú lái /), produces a character string that still contains the morphemes and syllables contained in the original word. If the reading system does have some tolerance for transpositions of morphemes and/or syllables, those dimensions could be partially contributing to any TC effects that might be observed. As we can see, there are numerous differences between logographic Chinese and alphabetic languages and, therefore, in order to provide a full examination of the present models of orthographic coding, it would appear to be a good idea to determine how well those models can explain data from nonalphabetic languages like Chinese.

Indeed, for various reasons, it’s possible that readers of nonalphabetic languages may be (empirically) differentially tolerant of position uncertainty than readers of alphabetic languages. In Chinese, for example, 97% of the two-character words do not make another word when the order of characters is reversed, and also four-character Chinese words are rare, and they normally do not have many orthographic neighbors. (In alphabetic languages, there are only 26 letters, whereas in Chinese, there are over 50,000 characters according to the Great Compendium of Chinese Characters (汉语大字典).) Hence, a given string of characters may have only one interpretation regardless of character order, meaning that accurate position coding may be less important (and, hence, not need to be as precise) in Chinese than in English. The present research project is an exploration of the current ideas concerning orthographic coding from the perspective that the orthographic coding processes may differ for different languages.

In the current literature, there are a large number of models of the orthographic coding process (e.g., Davis, 2010; Gómez, Ratcliff, & Perea, 2008; Grainger, Granier, Farioli, Van Assche, & Van Heuven, 2006; Norris & Kinoshita, 2012b; Norris, Kinoshita, & van Casteren, 2010; Schoonbaert & Grainger, 2004; Whitney & Marton, 2013; Whitney, 2001). Most of those orthographic coding models generally assume that orthographic processing in skilled readers involves representations at an abstract level. As Grainger (2018) has described, orthographic processing is the interface between lower level visual processing and high level language processing. Visual processing mainly involves obtaining information about the featural components of a word’s letters, and orthographic processing is mainly focused on deriving information about letter identities and letter positions. It makes sense therefore, that it would be computationally more effective, in alphabetic languages, to resolve any visual shape invariance issues at the letter level (N= 26 for alphabetic language like English) by relying on abstract letter respresentations instead of trying to resolve those issues at some other level (e.g., for the word level, N= 30,000+). That is, it would make sense that the orthographic coding system would be tuned to recognize letters (and, therefore, words) independently of the precise form that the visual input takes (e.g., MiXeD case vs. pure case, lowercase vs. UPPERCASE, as well as printed words vs. handwritten words - Gil-López, Perea, Moret-Tatay, & Carreiras, 2011). As a result, the abstract letter unit assumption is one that is incorporated into virtually all of the current models.

Chapters 2 and 3 in this dissertation will focus on the impact of transposing characters and, in particular, whether TC effects in logographic languages (Japanese Kanji will be used in one of the experiments) mirror those in alphabetic languages. At the same time, those experimens will involve investigations of the impact of altering the text orientation. Chapter 4 will provide a more direct assessment of the abstract letter unit idea in English by also investigating the impact of alterating the text orientation. More specifically, what the current models generally do not concern themselves with is the question of the influence of visuospatial coordinates on the nature of orthographic coding. The assumption is simply that the letters are rapidly transformed into an abstract code. In contrast, there are some perceptual learning accounts of orthographic coding that do assume such an influence. As will be discussed, those accounts would predict that orthographic effects of the sort investigated in Chapters 2 and 3 should decrease (but not necessarily vanish) when a TL stimulus is presented in what is an unfamiliar spatial orientation for readers (Dehaene et al., 2005; Grainger & Holcomb, 2009). This idea will be directly contrasted with the abstract letter unit account as described by Witzel et al. (2011). This account, which forms the basis for most of the current models of orthographic coding, argues that “the mechanism responsible for TL priming operates at an entirely abstract level, in which the visuospatial relationships of the letters are irrelevant” (p. 915). Based on this account, TL priming effects should be independent of the presented word’s orientation.

When considering this type of contrast, it is important to keep in mind that Chinese readers, like Japanese readers, do have some experience reading words in different orientations. Specifically, Chinese readers are familiar with left-to-right horizontal and top-to-bottom vertical text and, as well, they do have some (very limited) experience with right-to-left horizontal text while totally lacking experience with bottom-to-top text. Not only is the orientation of the Chinese characters diverse, but also the orientation of radicals inside the characters is multi-directional. Although Chinese characters are mainly arranged in a horizontal (“好”) or vertical configurations (“岗”) of radicals, more than 15 configurations exist in Chinese, such as A, ABC and so on, see examples in Figure 1. So Chinese character reading is completed through the use of a multiple-direction or 2-D scanning path (Chen & Tzeng, 1992). Therefore, due to the fact that Chinese readers have had perceptual experience with multiple character orientations, one would not necessarily expect to find a large impact of orientation on orthographic effects in Chinese. In English words, in contrast, all the word information is arranged in a left-to-right orientation, so word reading only involves a one-dimensional scanning path (although English readers do have limited experience in dealing with words written in different orientations - some words can appear vertically, for example, the word “HOTEL” may appear vertically in signs due to limited horizontal space), effects of orientation would be more likely to arise when reading English than when reading Chinese or Japanese.

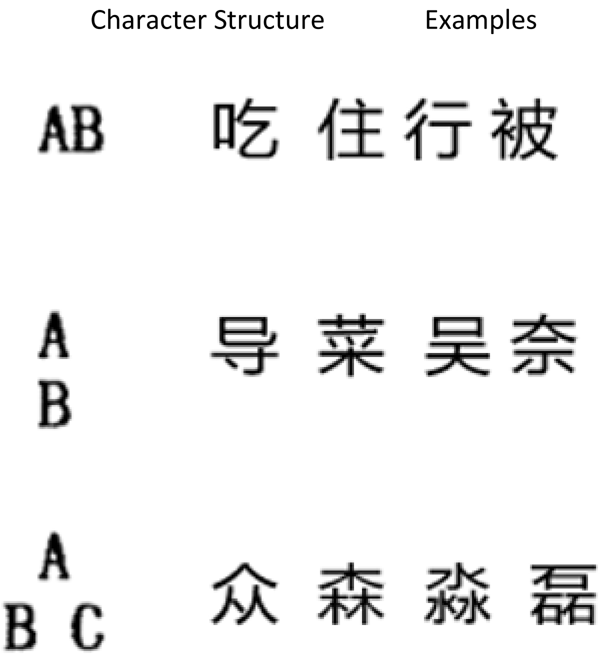


Figure 1: Chinese character structure in multi-dimensions

Because the orthographic coding process and potential differences in that process across logographic and alphabetical languages is the main issue that I will investigate in the present research project, it is important to clearly define the process and to explain how it is typically studied at the start. Orthographic coding refers to the component of the reading process that produces a representation reflecting both the letter identities and their positions in the word being read. Successful completion of this process is quite important in reading as, otherwise, readers could not distinguish orthographically similar words like “trial” and “trail”. The experimental paradigm most commonly used in investigations of this process is the masked priming paradigm. In this paradigm, a prime is presented for a brief period (e.g., 50 ms), so that, in general, participants cannot identify the prime or even notice its existence, followed by a target to which participants must respond by indicating whether this letter string is a real English word or nonword as quickly and as accurately as possible (Forster & Davis, 1984).

In investigations of orthographic coding, the prime and target will have some orthographic relationship between them (e.g., honse-HOUSE) and the size of the priming effect is typically taken as a measure of the degree of orthographic similarity of the prime and target. By varying the nature of the orthographic relationship between the two stimuli and noting the size of the priming effect that is produced, it is assumed that the nature of orthographic coding will become better understood.

There are a number of advantages of using the masked priming lexical decision task (which is the main experimental task that I used). Because it's normally impossible to consciously recognize the prime, the procedure allows one to investigate the effect of a particular prime-target relationship without participants' awareness of the manipulation. Therefore, the use of prime-driven response strategies is virtually impossible. However, there are some limitations to the use of this basic technique. One is that the masked priming LDT has also been shown to be influenced by phonological (Ferrand & Grainger, 1992; 1993) and lexical (Davis & Lupker, 2006) information and, therefore, results in this task do not always provide a uncontaminated view of the orthographic coding process.

In an attempt to provide a way of examining orthographic coding independent of phonological, lexical (and other) factors, Norris and Kinoshita (2008) introduced the masked priming same-different task (SDT). In this task, participants will see a reference stimulus above a forward mask (e.g., ######) for 1000 ms followed by a prime for 50 ms in the same position as the mask had been and then a target also in that same position. The participants' task is to decide whether the target is the same as or different from the reference stimulus. Just like in the masked priming LDT, the priming effects in the masked priming SDT seem to be invariant with respect to changes in visual inputs (e.g., font, size and uppercase/lowercase; García-Orza, Perea, & Muñoz, 2010; García-Orza, Perea, & Estudillo, 2011; Kinoshita & Norris, 2009). More importantly, the priming effects in this task have also been found to be independent of target frequency, lexicality and morphology (Duñabeitia, Kinoshita, Carreiras, & Norris, 2011; Kinoshita & Norris, 2009), suggesting that effects in the masked priming SDT might be purely orthographic (Kinoshita & Norris, 2009, 2010; Norris & Kinoshita, 2008). More specifically, although evidence of phonological influences (i.e., phonological priming effects in the SDT) have been reported in certain situations (e.g., Lupker, Nakayama, & Perea, 2015; Lupker, Perea, & Nakayama, 2015), this task does not appear to be influenced by lexical or morphemic/semantic information. Therefore, I also found it useful to use the masked priming same-different task in some of my experiments.

More specifically, with respect to the issues investigated in Chapter 2, which is a paper published in the *Journal of Experimental Psychology: Learning, Memory, and Cognition*, I used Chinese words in an effort to explore form priming effects in logographic languages when the words themselves are presented in various orientations. One hypothesis concerning the effects of visuospatial orientation on the orthographic coding process was proposed by Grainger and Holcomb (2009), who argued that letter detectors are based on their relative location with respect to eye fixation on the horizontal meridian. Letters in words that are not presented horizontally require a transformation of the retinotopic coordinates into a special coordinate system in order to allow the activation of open bigrams. For example, the open bigram ST in student would be coded as “s is on the left side of t. ” But in the vertically presented condition, the relevant ST bigram (“S is above T”) does not exist for readers of alphabetic languages, because those readers have very little experience with vertical text. So those readers would show smaller priming effects (if any) when the text is presented in an unfamiliar orientation because the special coordinate system required for successful reading of text in unfamiliar orientations is not formed.

In contrast, Witzel et al. (2011) argued that the mechanism responsible for form priming effects acts at a totally abstract level, a level at which visuospatial orientation no longer influences word processing. The letters and their positions are transformed from a spatial representation (either horizontal or vertical) into an abstract ordinal representation (first-to-last) which becomes the orthographic code. According to this hypothesis, people would show similar size form priming effects regardless of the presented text’s orientation, because the important processing would be done only after the input letters had been rapidly transformed into this first-to-last code.

This contrast between the perceptual learning account and the abstract letter account will be a crucial one in Chapters 2 and 4. The other main topic of this dissertation, the question of what is the nature of the orthographic coding pocess itself, will be discussed to some extent in Chapter 2 and will be the main issue investagatd in Chapter 3. Based on the data laid out in those chapters, I will unltimately discuss what my results say about the orthographic coding process and orthographic coding theories in the two languages, as well as how those theories might be improved in order to allow them to explain the data from Chinese readers.

Experiment 2.1 involved a masked priming paradigm examining TC and repetition priming effects for native Chinese readers using text presented in both standard horizontal and vertical orientations. In Experiment 2.2, I used the masked priming paradigm to test whether Chinese readers would show a priming effect when the stimuli were presented in a right-to-left horizontal orientation. In Experiment 2.3, I examined whether those effects might disappear when the target and prime were not presented in the same orientation. Specifically, in Experiment 2.3 the primes were presented in a right-to-left horizontal orientation with the targets being presented in a standard left-to-right horizontal orientation. Finally, in Experiment 2.4, primes and targets were presented in a bottom-to-top vertical orientation. Because words are not presented in this orientation in Chinese culture, according to any perceptual learning account, this is the one situation in which priming effects for Chinese readers should be diminished. In contrast, abstract letter/character unit accounts would not be inconsistent with any priming effects that might arise.

Chapter 2

2 The Impact of Text Orientation on Form Priming Effects with four-character Chinese words

2.1 Introduction

How do people successfully code letter identity and letter position information in a presented word? One approach to this issue involves proposing a “channel specific” coding scheme which is based on the idea that a letter’s specific position is directly coded, even before its identity is coded. The multiple read-out model (Grainger & Jacobs, 1996) and the interactive-activation model (McClelland & Rumelhart, 1981) are examples of models making this type of assumption. What is most relevant to the present discussion is that models making this assumption predict that transposed letter (TL) nonwords (e.g., jugde) are no more similar to their base words (i.e., JUDGE) than are substituted letter (SL) nonwords (e.g., jupte) and, therefore, the two types of nonwords should produce equivalent priming effects for their base word in masked priming experiments. More recent behavioral (e.g., Lété & Fayol, 2013; Perea & Lupker, 2003a; 2003b; 2004; Perea, Winskel, & Gómez, 2017), and event-related potential (ERP) results (e.g., Ktori, Kingma, Hannagan, Holcomb, & Grainger, 2015; Vergara-Martínez, Perea, Gómez, & Swaab, 2013), however, have failed to support this prediction. That is, many studies have shown that TL nonwords appear to be considerably more similar to their base words than SL nonwords are. For example, Perea and Lupker (2003a), among others, have reported a TL priming advantage, that is, that jugde is a better prime for JUDGE than junpe is. (Note that this difference could not be due to the orthographic overlap of the matching letters [i.e., ju- - e], because both jugde and junpe contain those letters in their correct positions.)

The alternative view that has emerged is that there is considerable flexibility in coding letter position as embodied in a number of newer models of orthographic coding/word recognition (Davis, 2010; Gómez, Ratcliff, & Perea, 2008; Norris, 2006; Whitney, 2001). This alternative approach can be thought of as one involving more “relative-position-based” coding schemes. Examples are the Open-bigram Models (Grainger & Van Heuven, 2003; Carol Whitney, 2001), the Spatial-Coding Model (Davis, 1999, 2010), and the Overlap Model (Gómez et al., 2008). In Open-bigram Models (Grainger & Van Heuven, 2003; Carol

Whitney, 2001), the basic assumption is that letter recognition involves detectors for sets of bigrams, both adjacent and nonadjacent bigrams. For example, the word JUDGE would activate bigram nodes for JU, UD, DG, GE, as well as JD, DE, UG. Reversed bigrams, such as DU would not be activated according to most versions of this type of model. This approach can explain TL priming effects, because TL primes share more bigrams with their target words than SL primes.

An alternative explanation is provided by the Spatial-Coding Model. Davis (1999, 2010) proposed a spatial-coding scheme in which letter position is encoded by the relative activation of position independent letter nodes. The initial letter has the lowest position code while the final letter has the highest position code with the set of letters forming a spatial pattern that represents the relative activation of letters in the different positions. The spatial codes for TL primes and their base words will be more similar than those of SL primes and those same base words because the codes of the TL primes and their base words contain the same letters and, therefore, the same letter units are being activated during processing.

TL priming effects can also be explained by the Overlap Model (Gómez et al., 2008). The Overlap Model assumes that the coded letter positions for each letter can be considered to be normally distributed over the different positions with the mean of the distribution being the letter's actual position. That is, in the word "judge", the letter "d" will be activated to the largest degree in position 3, and to a lesser degree in position 2 and 4 and even, to some degree, in position 1 and 5 (Gómez et al., 2008). The existence of the "g" and the "d" in the TL nonword prime jugde, therefore, provides some evidence that letter string being read is, indeed, JUDGE, evidence not provided by the SL nonword prime jupte.

Other models that can also explain TL priming effects include the Bayesian Reader Model (Norris & Kinoshita, 2012) and the Time and Retinotopic Space (LTRS) Model (Adelman, 2011). What the above models generally do not concern themselves with, however, is the question of the influence of visuospatial coordinates on the nature of orthographic coding. One hypothesis concerning the effects of visuospatial coordinates on word recognition was proposed by Grainger and Holcomb (2009), who argued that letter detectors are based on their relative location with respect to eye fixation on the horizontal meridian. Letters in words that are not presented horizontally require a transformation of the retinotopic coordinates into a special coordinate system in order to allow the activation of open bigrams. This special coordinate system for analyzing non-horizontal words develops through exposure experience and is affected by the characteristics of the language being read. This type of account is essentially a perceptual learning account.

Dehaene et al. (2005) also posit that perceptual learning mechanisms are involved in how the orthographic code is created as they propose that there are dedicated neurons which only represent frequent, informative letters and bigrams. For instance, people may have detectors for CH, which often appears in English words, but not for CZ, which rarely appears in English words. This proposal is supported by the finding that early retinotopic areas produce more activation in response to letters than to rotated versions of letters (Chang et al., 2015). These types of hypotheses suggest that form priming effects (e.g., the TL priming effect) would be altered by changing the text's orientation.

In contrast, Witzel et al. (2011) argued that the mechanism responsible for form priming effects acts at a totally abstract level, a level at which visuospatial orientation no longer influences word processing. The letter positions are transformed from a spatial representation (either horizontal or vertical) into an abstract ordinal representation (first-to-last) which becomes the orthographic code. According to this hypothesis, people would show form priming effects regardless of the presented text's orientation, because the input letters would be rapidly transformed into this first-to-last code, and that code would then be used to access the lexicon regardless of the visuospatial orientation of the original stimulus.

In order to determine which type of hypothesis provides a better explanation of the nature of the orthographic code, Witzel et al. (2011) examined TL (and transposed character–TC) priming effects for Japanese-English bilinguals and English monolinguals using a masked priming paradigm. These two groups seemed to provide a fruitful contrast because Japanese readers are used to reading both horizontally presented and vertically presented text whereas English readers are not. The question was whether the two groups showed TL/TC priming effects when the stimuli were presented in both horizontal and vertical orientations. As expected, Japanese readers showed TL/TC priming effects in both horizontal and vertical presentation conditions. More centrally, native English speakers also showed TL priming effects when the text was presented in the vertical orientation (even though they lacked experience with vertical text), providing support for abstract letter unit accounts.

Perea, Marcet, and Fernández-López (2018) extended this investigation using Spanish words by comparing the magnitude of form priming effects in two different vertical orientations, marquee and 90° rotated orientations. Those authors found significant and equivalent masked form priming effects for primes and targets presented in the two orientations. These results are also potentially inconsistent with perceptual learning accounts but are quite consistent with approaches that treat letter/character codes as abstract representations (i.e., not tied to retinal positions).

In contrasting these two types of accounts, what is relevant to note, however, is that perceptual learning accounts do not directly predict null priming when a letter string is presented in a unique orientation. Even if the stimulus is rotated, causing the mental representation to be rotated, processing of the stimulus will continue and will normally be successful. What is the key prediction of these types of accounts is that there will be larger priming effects for canonically (i.e., horizontally) presented letter strings than letter strings presented in other orientations due to the fact that noncanonical strings cannot take advantage of structures such as the neurons that are assumed to be dedicated to processing familiar letter pairs. Note also that these types of accounts make an additional prediction, that is, that transposition effects will be larger for horizontally presented letter strings (i.e., stimuli able to take advantage of such neurons) than other types of horizontally presented stimulus strings, for example, strings of symbols such as &%$#@, a prediction that has been supported in the literature (e.g., Duñabeitia, Dimitropoulou, Grainger, Hernández, & Carreiras, 2012; Massol, Duñabeitia, Carreiras, & Grainger, 2013). Note further that the specific comparison between horizontally presented words and nonhorizontally presented words was not evaluated either by Perea et al. (2018) or by Witzel et al. (2011) for their English readers.

Witzel et al.’s (2011) Japanese words were written in Katakana script. Although Katakana script is syllabic rather than alphabetic, it is much closer to alphabetic script than logographic scripts like Chinese. Each Katakana character represents a syllable or a combination of syllables (i.e., a *mora*), and, hence, represents a phonological unit. In contrast, Chinese characters have more complex internal structures, which are made up of between 1 and 36 strokes which are usually arranged into subcharacter “radicals”, with those radical units being related directly to semantic and phonological information (Taft, Zhu, & Peng, 1999). Nonetheless, Chinese readers do show TC and other types of form priming effects (Gu & Li, 2015; Gu et al., 2015; Taft, Zhu, et al., 1999; J. Yang, 2013). Therefore, Chinese allows an opportunity to determine if the results Witzel et al. and Perea et al. (2018) reported for alphabetic and syllabic languages can be extended to logographic languages. Since Perea et al. reported no difference between marquee and rotated words, I chose to use the marquee format for the vertical presentations in order to maintain consistency with Witzel et al.

What is worth noting at this point, however, is that most characters in Chinese are both syllables and morphemes (Zhou, Marslen-Wilson, Taft, & Shu, 1999). Thus, the possibility exists that what would appear to be form priming effects in Chinese may not be purely orthographic, but may also be due to overlap at the morphemic and/or syllabic levels. That is, even if Chinese characters are transposed, they are, typically, able to provide appropriate morphemic and syllabic information even though they now appear in incorrect positions. For example, 突如其来(/tū rú qí lái/, suddenly) is a Chinese four character word that, when the middle characters are transposed 突其如来(/tū qí rú lái /), produces a character string that still contains the morphemes and syllables contained in the target word. If the reading system does have some tolerance for transpositions of morphemes and/or syllables, those dimensions could be partially contributing to any TC priming effects that might be observed. I will return to this issue near the end of this chapter.

The fact that the existence of TC priming effects has been established in Chinese is important because TC priming effects are not universal. Velan and Frost (2009), for example, found that Hebrew TC primes did not facilitate target word processing but, in fact, produced an inhibitory effect when the transposition of adjacent characters formed a legal root morpheme. This result has been taken to mean that the lexical space in Hebrew is encoded according to morphological root families, rather than according to orthographic structure, which may also be true of Chinese. Indeed, Grainger and Holcomb (2009) have argued that the special coordinate system is likely to be influenced by the characteristics of the language being investigated. It is, therefore, important that form priming effects and, in particular, TC priming effects, have been observed in Chinese as those types of results make the question of whether the effects vary as a function of orientation a viable one to investigate.

In the present research, therefore, I used Chinese words in an effort to explore form priming effects in logographic languages as a function of visuospatial orientation. What's also important to note is that Chinese readers, like Witzel et al.'s (2011) Japanese readers, do have some experience reading words in different orientations. Specifically, Chinese readers are familiar with left-to-right horizontal and top-to-bottom vertical text and, as well, they do have some (very limited) experience with right-to-left horizontal text while totally lacking experience with bottom-to-top text.

Experiment 2.1 involved a masked priming paradigm examining TC and repetition priming effects for native Chinese readers using text presented in both standard horizontal and vertical orientations. Based on the results from Witzel et al. (2011), one would expect to find significant priming effects in both orientations. In Experiment 2.2, I used the masked priming paradigm to test whether Chinese readers would show a priming effect when the stimuli were presented in a right-to-left horizontal orientation. According to a perceptual learning account, although Chinese readers might show priming when the text is presented in a vertical orientation, there should be substantially less evidence of priming effects when the text is presented in this rather unfamiliar right-to-left orientation. In contrast, according to abstract letter/character unit accounts, there is no obvious reason that priming effects would not be found in any orientation in which reading can proceed somewhat normally (e.g., the right-to-left horizontal orientation). To jump ahead, priming was found with right-to-left text in Experiment 2.2 and, in Experiment 2.3, I examined whether those effects might disappear when the target and prime were not presented in the same orientation. Specifically, in Experiment 2.3 the primes were presented in a right-to-left horizontal orientation with the targets being presented in a standard left-to-right horizontal orientation. Finally, in Experiment 2.4, primes and targets were presented in a bottom-to-top vertical orientation (which does not exist in Chinese culture). According to any perceptual learning account, there is no possibility that priming effects due to the existence of dedicated neurons would emerge, while abstract letter/character unit accounts would not be inconsistent with any priming effects that might arise.

2.2 Experiment 2.1

2.2.1 Method

Participants. Forty native Chinese speakers who had normal or corrected-to-normal vision participated in this experiment. All indicated that they were highly proficiency in reading Simplified Chinese. All were undergraduate students at Hunan University of Science and Technology (Xiangtan, Hunan, China). Twenty participants received the horizontal text condition first, and 20 participants received the vertical text condition first. All the participants were given a small gift for their participation.

Materials. The stimuli for Experiment 2.1 were four-character simplified Chinese words. One hundred ninety-two low frequency words were chosen to serve as target words and another 192 low frequency words were chosen to serve as unrelated word primes. All of those words were selected from the *SUBTLEX-CH* database (Cai & Brysbaert, 2010). For the target words, their mean word frequency (per million) was 4.37 (range = 1.25-51.63). For the unrelated word primes, their mean word frequency (per million) was 4.41 (range = 1.22-37.83). All of the frequency values were obtained from the *SUBTLEX-CH* database (Cai & Brysbaert, 2010). There is no significant difference in frequency between the target words and the unrelated word primes, $t(382) = -0.07$, $p = 0.947$.

In the repetition condition, the related prime was the target itself, and the control prime was the unrelated word prime selected for that target (e.g., 有所不同(ABCD)-有所不同(ABCD) vs.总的来说(EFGH)-有所不同(ABCD)). The primes and targets used different font styles and sizes (35-point Arial font for primes and 40-point Song font for targets). In the TC condition, the related primes were character strings in which the two middle characters in the target were transposed, whereas in the control condition for the TC condition (the SC condition), the two middle characters were substituted with two new characters (e.g., 有不所同(ACBD)-有所不同(ABCD) vs. 有扑走同(AJKD)-有所不同(ABCD)). The target words were divided into two sets and their use in the horizontal vs vertical orientation conditions was counterbalanced. In addition, there were 4 counterbalanced lists in each orientation condition with 24 stimuli in each condition. I also created 384 orthographically legal nonwords (half of them to serve as target nonwords, the other half to serve as unrelated nonword primes for the nonword targets). These nonword stimuli were derived from the nonwords found in the Chinese Lexicon Project (Tse et al., 2017). The primes for the nonword targets were created in a similar fashion as the primes for the word targets (¼ were repetition nonword primes, ¼ were unrelated nonword primes, ¼ were TC nonword primes and ¼ were SC nonword primes), except that there was only one list of primes and targets.[1] For the word stimuli, the primes and their associated targets are listed in the Appendix.

Procedure. The participants were seated in a quiet room for testing. Eprime 2.0 software was used for data collection (Psychology Software Tools, Pittsburgh, PA; see Schneider, Eschman, & Zuccolotto (2002)). Each trial began with a mask (which consisted of eight hash marks ########) presented for 500 ms, followed by a prime for 50 ms, and then the target which was presented for 3000 ms or until the participant responded. All the stimuli were presented in the center of the screen. Text presentation orientation (horizontal vs. vertical) was constant within a block and the order of the blocks was counterbalanced over participants (see Figure 1 for examples of a word presented in the various text orientations used in these experiments). Before the start of each block, participants performed 16 practice trials involving the stimulus orientation to be used in that block. Participants were asked to decide whether each presented (target) character string is a meaningful real word or a meaningless nonword. They were asked to press the "J" button if the presented target is a word and the "F" button if it is a nonword as quickly and as accurately as possible. This research was approved by the Western University REB (Protocol # 108835).

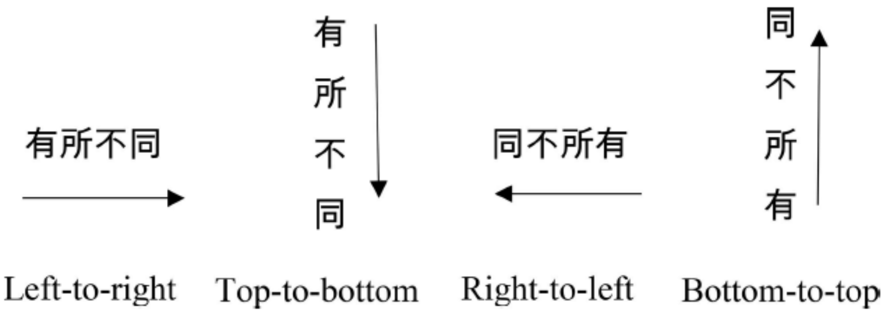


Figure 2: Examples of Chinese text presented in different text orientations

2.2.2 Results

Latencies for incorrect responses were excluded from the latency analyses (3.8% of the data), as were latencies that were shorter than 300 ms (0.1% of the data). The latencies from the correct trials and the error rates were analyzed using generalized linear mixed-effects modeling in R version 3.4.3 ("R Core Team," 2015), treating subjects and items as random effects and treating Orientation (horizontal vs. vertical), Prime Type (repetition vs. transposition) and Priming (related vs. control) as fixed effects (Baayen, 2008; Baayen, Davidson, & Bates, 2008). Post hoc analyses were conducted using the lsmeans package, version 2.27-61 (Russell V Lenth, 2016), with Tukey's Honestly Significant Difference (HSD) adjustment for multiple comparisons. Prior to running the model, R-default treatment contrasts were changed to sum-to-zero contrasts (i.e., contr.sum) to help interpret lower-order effects in the presence of higher-order interactions (Levy, 2014; Singmann & Kellen, 2017). The model was fit by maximum likelihood with the Laplace approximation technique. The lme4 package, version 1.1-15 (Bates, Mächler, Bolker, & Walker, 2015), was used to run the generalized linear mixed-effects model and obtain probability values.

A generalized linear mixed-effects model was used in the latency analyses in all the present experiments instead of a linear mixed-effects model because generalized linear models, unlike linear models, do not assume a normally distributed dependent variable and can, therefore, better accommodate the typically positively skewed distribution of RT data (Balota, Aschenbrenner, & Yap, 2013; Lo & Andrews, 2015).[2] A Gamma distribution was used to fit the raw RTs, with an identity link between fixed effects and the dependent variable (Lo & Andrews, 2015). Note that convergence tests for generalized linear mixed-effects models in the current version of lme4 tend to generate many false positives (Bolker, 2018).[3] The statistical model for the latency analysis was: RT = glmer (RT ~ orientation * primetype * priming + (1|subject) + (1|item), family = Gamma (link = "identity")). The statistical model for the error rate analysis was: Accuracy = glmer (accuracy ~ orientation * primetype * priming + (1|subject) + (1|item), family = "binomial"). The mean RTs (in milliseconds) and percentage error rates for both the horizontal and vertical orientations are shown in Table 1 for the word targets.

Table 1: Mean Lexical Decision Latencies (RTs, in Milliseconds) and Percentage Error Rate for Words in Experiment 2.1

	Repetition		TC	
	RT	%E	RT	%E
Horizontal				
Related	557	2.5	575	3.3
Control	637	3.8	628	5.8
Priming	80	1.3	53	2.5
Vertical				
Related	640	2.4	660	3.3
Control	711	4.9	698	4.5
Priming	71	2.5	38	1.2

Note. TC= transposition condition; RT= reaction time; %E=percentage error rate. The control primes for repetition primes were unrelated primes and for TC primes the control primes were substitution primes. The overall mean RT and error rate of the nonword targets in horizontal orientation were 719 ms and 3.8% respectively; The overall mean RT and error rate of the nonword targets in vertical orientation were 820 ms and 3.3% respectively.

Word trial latencies. The default model failed to converge even when fitting was restarted from the apparent optimum. I then proceeded to re-run the model using all available optimizers. Because all optimizers returned very similar values, it seemed likely that the convergence warnings were false positives (see lme4 convergence help page). The results reported below are the results from the BOBYQA optimizer, which managed to converge.

There was no significant main effect of Prime Type, *ß* = -1.562, *SE* = 1.516, *z* = -1.03, *p* = .303, however, a significant main effect of Priming was observed, *ß* = -29.757, *SE* = 1.474, *z* = -20.19, *p* < .001. Responses following related primes were significantly faster (608 ms) than responses following control primes (669 ms). The main effect of Orientation was also significant, *ß* = -33.828, *SE* = 1.457, *z* = -23.21, *p* < .001, as latencies were longer with vertical text (677 ms) than with horizontal text (599 ms). The interaction between Priming and Prime Type was significant, *ß* = -7.573, *SE* = 1.467, *z* = -5.16, *p* < .001, with the repetition priming effect being significantly larger than the TC priming effect. In the repetition priming condition, latencies following repetition primes (599 ms) were significantly faster than latencies following unrelated primes (674 ms), *ß* = -37.330 *SE* = 2.081, *z* = -17.94, *p* < .001. When considering the TC priming effect, the control condition (i.e., the substituted character (SC) primes) led to significant slower latencies (663 ms) than the TC primes (617 ms), *ß* = -22.184, *SE* = 2.078, *z* = -10.68, *p* < .001. No other effects reached significance (all *ps* > .10).

Word trial accuracy.

The main effect of Prime Type was significant, indicating an advantage for the repetition conditions (3.4%) over the TC conditions (4.2%), *ß* = 0.132, *SE* = 0.064, *z* = 2.06, *p* = .040. In addition, there was a Priming effect with the related primes (2.9%) leading to fewer errors than the unrelated primes (4.7%), *ß* = 0.280, *SE* = 0.065, *z* = 4.33, *p* < .001. Neither the main effect of Orientation nor any interaction was significant (all *ps* >.10).

Nonword trial latencies.

The default model converged after restarting it from the apparent optimum. The only significant effect was that of Orientation, *ß* = -46.605, *SE* = 1.864, *z* = -25.01, *p* < .001, with faster responses to horizontally presented nonwords (719 ms) than to vertically presented nonwords (820 ms). No other main effect or interactions reached significance (all *ps* > .10).

Nonword trial accuracy.

The main effect of Priming was significant, with a small but significant reverse priming effect, *ß* = -0.207, *SE* = 0.082, *z* = -2.52, *p* = .012. Control primes produced a slightly smaller error rate (2.8%) than related primes (4.2%), The only significant interaction was the Priming by Orientation interaction, *ß* = -0.181, *SE* = 0.063, *z* = -2.89, *p* = .004, indicating that a significant reverse effect of Priming arose in the horizontal orientation condition (*ß* = -0.388, *SE* = 0.103, *z* = -3.79, *p* = .003), but not in the vertical orientation condition (*ß* = -0.026, *SE* = 0.104, *z* = -0.25, *p* = .960). There were no other main effects or interactions (all *p*s >.05).

2.2.3 Discussion

The results of Experiment 2.1 were quite similar to those of Witzel et al. (2011): Chinese native readers showed significant repetition and TC priming effects when stimuli were presented in both horizontal and vertical orientations. Unlike Japanese readers, however, Chinese readers were faster (78 ms) when processing horizontal text than vertical text as well as showing a small, although nonsignificant, overall priming advantage (12 ms) with horizontal text. This pattern is consistent with the idea that Chinese readers may have had somewhat more experience in reading horizontal text than vertical text and, therefore, may have a reading system that is better tuned for processing horizontal text. The main point to be taken from Experiment 2.1, however, is that the finding that both repetition and TC priming effects were obtained in both text orientations, orientations that are familiar to Chinese readers, is consistent with both abstract letter/character unit accounts and perceptual learning accounts. The way to distinguish between accounts, therefore, is to examine the nature of priming effects for Chinese readers when processing text presented in a rarely experienced orientation, for example, a right-to-left horizontal orientation.

As noted, it is not the case that Chinese words are never written in the right-to-left horizontal orientation. Text of this nature occurs on signs at some temples and in the top scroll in a couplet. However, the right-to-left horizontal orientation is rarely experienced in modern Chinese culture. Therefore, a perceptual learning account would predict that Chinese readers should show little evidence of repetition or TC priming when reading text written in a right-to-left orientation, while effects of this sort would not be inconsistent with a generic abstract letter/character unit account. What should be noted at this point is that right-to-left primes do not appear to produce priming of either left-to-right or right-to-left targets in English (Davis, Kim, & Forster, 2008).

2.3 Experiment 2.2

2.3.1 Method

Participants. Forty-four Chinese native speakers who had normal or corrected-to-normal vision participated in this experiment. As in Experiment 2.1, all indicated that they were highly proficiency in reading Simplified Chinese. They were all graduate or undergraduate students either from Western University (London, Ontario, Canada) or Hunan University of Science and Technology (Xiangtan, Hunan, China). They were paid $5 for their participation or given a small gift. None had participated in the Experiment 2.1.

Materials. Ninety-six of the target nonwords (and their unrelated word primes) used in Experiment 2.1 were used in Experiment 2.2. The word frequency was matched between the target words and unrelated word primes. Twenty-four targets were primed by a repetition prime (e.g., 同不所有(DCBA)-同不所有(DCBA)), 24 by an unrelated word (e.g., 说来的总(HGFE)-同不所有(DCBA)), 24 by a TC prime (e.g., 同所不有(DBCA)-同不所有(DCBA)) and 24 by an SC prime (e.g., 同走扑有(DJKA)-同不所有(DCBA)). There were 4 counterbalanced lists for the word stimuli. Ninety-six of the target nonwords (and their unrelated nonword primes) used in Experiment 2.1 were used in Experiment 2.2. The primes for the nonword targets were created in a similar fashion as the primes for the word targets, except that there was only one list of primes and targets. All the other details were the same as in Experiment 2.1.

Procedure. The procedure was the same as in Experiment 2.1. The only difference was that all the stimuli, both primes and targets, were presented in the right-to-left horizontal orientation only. Before the start of the experiment, participants performed 16 practice trials with right-to-left oriented primes and targets.

2.3.2 Results

Latencies for incorrect responses were excluded (3.7% of the data), as were latencies that were shorter than 300 ms (0.2% of the data). Data were collapsed across study location (Canada vs. China) due to the fact that there was no three-way interaction between Location, Prime Type and Priming. The statistical model for the latency data was: RT = glmer (RT ~ primetype * priming + (1|subject) + (1|item), family = Gamma (link="identity"). In the error rate analysis, the statistical model was: Accuracy = glmer (accuracy ~ primetype * priming + (1|subject) + (1|item), family = "binomial"). The other details were same as in Experiment 2.1. The mean RTs (in milliseconds) and percentage error rates for this experiment are shown in Table 2 for the word targets.

Table 2: Mean Lexical Decision Latencies (RTs, in Milliseconds) and Percentage Error Rate for Words in Experiment 2.2

	Repetition		TC	
	RT	%E	RT	%E
Right-to-left Horizontal				
Related	810	3.4	815	3.3
Control	893	4.0	856	4.8
Priming	83	0.6	41	1.5

Note. TC= transposition condition; RT= reaction time; %E=percentage error rate. The control primes for repetition primes were unrelated primes and for TC primes the control primes were substitution primes. The overall mean RT and error rate of the nonword targets were 1068 ms and 5.6% respectively.

Word trial latencies. There was a significant main effect of Prime Type, *ß* = 8.812, *SE* = 2.922, *z* = 3.02, *p* = .003, and a significant main effect of Priming, *ß* = -29.907, *SE* = 3.097, *z* = -9.66, *p* < .001, as responses were faster overall in the TC conditions and for related primes. The interaction between Priming and Prime Type was also significant, *ß* = -8.342, *SE* = 3.058, *z* = -2.73, *p* = .006, with the repetition priming effect (83 ms) being significantly larger than the TC priming effect (41 ms). In the post hoc analysis, there was a significant repetition priming effect, *ß* = -38.25, *SE* = 4.468, *z* = -8.56, *p* < .001. In the TC condition, the TC primes led to significantly shorter latencies than the SC primes, *ß* = -21.565, *SE* = 4.234, *z* = -5.09, *p* < .001.

Word trial accuracy. There was a marginal effect of Priming (*ß* = 0.155, *SE* = 0.085, *z* = 1.81, *p* = .070), indicating a tendency for targets following related primes to elicit fewer errors (3.4%) than targets following control primes (4.4%). Neither the main effect of Prime Type nor the interaction approached significance (all *ps* >.10).

Nonword trial latencies and accuracy. Neither of the main effects nor the interaction approached significance in either analysis (all *ps* >.05).

2.3.3 Discussion

The results of Experiment 2.2 essentially paralleled those of the horizontal and vertical orientation conditions in Experiment 2.1. That is, not only were both repetition and TC priming effects observed, the priming effect sizes were very similar in size to those in Experiment 2.1. While being consistent with a generic abstract letter/character unit account, these results provide little support for a perceptual learning account of repetition and TC priming effects. Any perceptual learning accounts of these effects would predict that these effects would not arise or would be quite weak when the stimuli are presented in such an unfamiliar orientation.

An alternative explanation of the effects in Experiment 2.2, and one that would not necessarily be problematic for a perceptual learning account, is that those effects might have been an artefact of the demands of the task. Specifically, in line with a transfer-appropriate processing idea (e.g., Franks, Bilbrey, Lien & McNamara, 2000; Kolers & Perkins, 1975; Kolers & Roediger, 1984), one could argue that, in order to deal with unfamiliar right-to-left targets, participants may have developed some sort of processing strategy for mentally reversing the order of the characters in the target, a strategy that was then also applied to prime processing. Experiment 2.3 was an attempt to examine this idea. The specific question was, will Chinese readers still show repetition and TC priming effects when the target is presented in the conventional left-to-right orientation following a right-to-left oriented prime?

2.4 Experiment 2.3

2.4.1 Method

Participants. Sixty Chinese native speakers who had normal or corrected-to-normal vision and who reported that they were highly proficient in reading Simplified Chinese participated in this experiment. They were all undergraduate students from Western University (London, Ontario, Canada) who participated for course credit in their Introductory Psychology course. None had participated in the previous experiments.

Materials. One hundred of the target words (and their unrelated word primes) used in Experiment 2.1 were used in Experiment 2.3. The word frequency was matched between the target words and unrelated word primes. Twenty targets were preceded by a (backward) repetition prime, that is, one that involves the same characters but presents them in a right-to-left orientation (e.g., 同不所有(DCBA)-有所不同(ABCD)) and 20 were preceded by an unrelated prime (i.e., a totally different word) that was also presented in the right-to-left orientation (e.g., 说来的总(HGFE)-有所不同(ABCD)). Three different prime types were used to investigate the TC priming effect. Twenty pairs involved what would be thought of as a (backward) classic TC prime, that is, one in which the prime is presented right-to-left but the middle two characters are transposed (e.g., 同所不有(DBCA)-有所不同(ABCD)). Note, however, that doing so creates a prime in which the middle two characters are in the same position in the prime and target and, therefore, is technically a prime involving a transposition of the first and fourth characters. Twenty pairs involved what could be thought of as a (backward) classic SC prime, that is one in which the prime was presented in a right-to-left orientation and the middle two characters are substituted (e.g., 同走扑有(DJKA)-有所不同(ABCD)). Finally, 20 primes were used that may be a better control for evaluating TC priming. These primes involved an external substitution prime which maintains the middle two characters of the prime in their appropriate positions (as in the classic TC primes discussed above) but replaces the first and fourth characters of the target (e.g., 走所不扑(JBCK)-有所不同(ABCD)).

There were 5 counterbalanced lists for the word stimuli. One hundred of the target nonwords (and their unrelated nonword primes) used in Experiment 2.1 were used in Experiment 2.3. Just as in the word conditions, these nonword targets were preceded by five different types of primes and, as in the previous experiments, there was only one list of nonword primes and targets. The other details were the same as in Experiment 2.1.

Procedure. The procedure was the same as Experiment 2.1, the only difference being that all the primes were presented in the right-to-left horizontal orientation, while all the targets were presented in the normal (left-to-right) horizontal orientation. Before the start of the experiment, participants performed 20 practice trials involving right-to-left oriented primes and left-to-right oriented targets.

2.4.2 Results

Latencies for incorrect responses were excluded (2.8% of the data), as were latencies that were shorter than 300 ms (0.2% of the data). Unlike Experiment 2.1 and Experiment 2.2, the design of Experiment 2.3 involved a single fixed effect, Prime Type, with five levels (repetition, unrelated, classic TC, classic SC, external SC). The function Anova in the car package version 2.1-2 (Fox & Weisberg, 2016) was used to test the significance of the Prime Type factor. The statistical model for the latency data was: RT = glmer (RT ~ primetype + (1|subject) + (1|item), family = Gamma(link = "identity")). In the error rate analysis, the model was: Accuracy = glmer (accuracy ~ primetype + (1|subject) + (1|item), family = "binomial"). The other details were the same as in Experiment 2.1. The mean RTs (in milliseconds) and percentage error rates for Experiment 2.3 are shown in Table 3 for the word targets.

Table 3: Mean Lexical Decision Latencies (RTs, in Milliseconds) and Percentage Error Rate for Words in Experiment 2.3

Condition	RT	%E
Repetition prime	664	1.8
Unrelated prime	716	3.7
Classic Transposed prime	648	2.7
Classic Substitution prime	704	3.5
External Substitution prime	699	3.1

Note. The overall mean RT and error rate of the nonword targets were 881 ms and 3.6% respectively.

Word trial latencies. The default model converged after restarting it from the apparent optimum. There was a main effect of Prime Type, $\chi^2 = 185.98$, $p < .001$. In the post hoc analysis, participants showed a significant repetition priming effect (52 ms), *ß* = -53.607, *SE* = 6.715, *z* = -7.98, *p* < .001. Significant TC priming was observed when comparing the classic TC prime condition with both the external SC prime condition (51 ms), *ß* = 48.013, *SE* = 5.252, *z* = 9.14, *p* < .001, and the classic SC prime condition (56 ms), *ß* = 54.252, *SE* = 5.507, *z* = 9.85, *p* < .001. The classic SC prime condition did not differ from the external SC prime condition, *ß* = -6.239, *SE* = 5.300, *z* = -1.18, *p* = .765. Note that the classic TC prime condition produced latencies that were numerically, but not significantly, shorter than those in the repetition prime condition, *ß* = 13.555, *SE* = 5.832, *z* = 2.32, *p* = .137. Finally, the mean latency in the unrelated prime condition was longer than the mean latency in the external SC prime condition, *ß* = -19.149, *SE* = 5.980, *z* = -3.20, *p* = .012, but did not differ from the mean latency in the classic SC prime condition, *ß* = -12.911, *SE* = 6.148, *z* = -2.10, *p* = .220.

Word trial accuracy.

The main effect of Prime Type was significant, $\chi^2 = 10.224$, *p* = 0.037. In the post hoc analysis, participants showed a significant repetition priming effect (1.9%), *ß* = 0.817, *SE* = 0.279, *z* = 2.93, *p* = .028. Repetition primes (1.8%) also elicited less errors than classic SC primes (3.5%), although only marginally so, *ß* = -0.762, *SE* = 0.281, *z* = -2.71, *p* = .052.

Nonword trial latencies.

The default model converged after restarting it from the apparent optimum. There was a main effect of Prime Type, $\chi^2 = 11.86$, *p* = .018. The post hoc analysis revealed that, compared to repetition primes (899 ms), external SC primes (877 ms) led to faster latencies, *ß* = -20.632, *SE* = 7.170, *z* = -2.88, *p* = .033, and so did (although only marginally so) classic TC primes (875 ms), *ß* = -21.289, *SE* = 7.907, *z* = -2.69, *p* = .055. No other contrasts reached significance (all *p*s >.1).

Nonword trial accuracy.

The main effect of Prime Type was not significant, $\chi^2 = 6.01$, *p* =.199.

2.4.3 Discussion

In order to avoid inducing participants to adopt a processing strategy for dealing with unfamiliar right-to-left targets, one based on mentally reversing the order of the characters in the target which then would also be applied during prime processing, the targets in Experiment 2.3 were presented in the conventional left-to-right orientation. The most important result in this experiment was that there was a significant (backward) repetition priming effect. Repetition primes presented in the completely opposite (right-to-left) orientation primed targets presented in the standard left-to-right horizontal orientation.

Experiment 2.3 also provided evidence of a (backward) TC priming effect when measured against both of the control conditions. As these patterns generally parallel those from Experiment 2.2, a reasonable conclusion would be that the results in Experiment 1.2 were not due to participants adopting a strategy involving a mental reversal of the order of the target's (and prime's) characters. Rather, they are more likely due to the abstract nature of representations in the orthographic code.

The main question of Experiment 2.3 concerned whether right-to-left primes produce priming for left-to-right targets in Chinese, just as they did for right-to-left targets in Experiment 2.3 (but not as what they appear to do in English – Davis, Kim & Forster, 2008). Whereas the answer is that they do produce priming, it may be worth noting that the size of the "repetition" effect in Experiment 2.3 (52 ms) was slightly smaller than the size of the parallel effect in Experiment 2.2 (83 ms). Part of that difference was likely due to the fact that responding was approximately 150 ms faster in Experiment 2.3, although that is probably not the only reason for the difference in the effect sizes. Rather, right-to-left primes are probably at least a bit more orthographically similar to the right-to-left targets used in Experiment 2.2 than to the left-to-right targets used in Experiment 2.3.

What is also potentially relevant is that, in contrast to the results in Experiment 2.2, the "repetition" priming effect and what could be considered the TC priming effect were equivalent in Experiment 2.3. In an attempt to gain a bit more of an understanding of the principles involved here, it may be of some value to examine the impact of transposing characters in Experiment 2.3 a bit more closely.

Essentially, right-to-left oriented primes with their middle two characters then transposed (what are being called classic TC primes - e.g., DBCA) led to faster latencies than both what are being called classic SC primes (e.g., (DJKA) and primes involving the same middle characters in the same positions as in the target but having different exterior characters (JBCK). As noted, these TC priming effects are a bit hard to characterize because all three of these prime types can be interpreted in more than one way. As a result, it's not at all clear which of these two latter prime types would be the most appropriate control condition in this situation (or, if neither of these is appropriate, what the appropriate condition would be). That is, the DBCA-DJKA contrast could be characterized as representing the value of having correct characters in the two middle positions rather than representing the impact of a right-to-left written TC prime. Similarly, the DBCA-JBCK contrast could be characterized as representing the impact of transposing the first and fourth characters in a left-to-right prime.

When thought about in those ways, however, one seems to arrive at an illogical conclusion. This second contrast (DBCA-JBCK) produced a 51 ms priming effect (699-648) which, when thought about as representing the impact of a left-to-right oriented prime, implies that transposing the exterior two characters (rather than replacing them) was quite impactful. In contrast, the difference between the classic SC prime condition and the completely unrelated condition (DJKA-HGFE) was a nonsignificant 12 ms (704-716) suggesting that the impact of transposing the two exterior characters is minimal at best. Needless to say, it's hard to reconcile these two conclusions. Therefore, in the present situation (i.e., in Chinese), the more reasonable conclusion is that there is something crucial about the prime and target sharing all their characters even if those characters are not in the same positions in the prime and target (i.e., the (backward) classic TC prime, DBCA, or the (backward) repetition prime, DCBA, work well whereas primes containing 2 of the 4 target characters, JBCK and DJKA, do not).

In Experiment 2.4, we sought to push the contrast between perceptual learning and abstract letter/character unit accounts one step further by presenting the primes and targets in a completely unfamiliar bottom-to-top orientation. According to any perceptual learning account, there should be very little evidence of priming effects from these prime-target pairs, whereas a generic abstract letter/character unit account would seem to have the ability to explain such an effect.

2.5 Experiment 2.4

2.5.1 Method

Participants. Thirty-four Chinese native speakers who had normal or corrected-to-normal vision and who reported that they were highly proficient in reading Simplified Chinese participated in this experiment. They were all undergraduate students from Western University (London, Ontario, Canada) who participated for course credit in their Introductory Psychology course. Fourteen of these participants had participated in Experiment 2.3 in the same session.

Materials. Ninety-six of the target words (and their unrelated word primes) used in Experiment 2.1 were used in Experiment 2.4. The word frequency was matched between the target words and the unrelated word primes. Unlike in Experiment 2.1, only TC priming was investigated with 48 targets being primed by a TC prime (e.g., 有不所同(ACBD)-有所不同(ABCD)) and 48 by an SC prime (e.g., 有扑走同(AJKD)-有所不同(ABCD)). There were 2 counterbalanced lists for word stimuli. Ninety-six of the target nonwords (and their unrelated nonword primes) used in Experiment 2.1 were used in Experiment 2.4. As with the word targets, the nonword targets were preceded either by a TC prime or an SC prime and, as in previous experiments, only one list of nonword primes and targets was used. The other details were the same as in Experiment 2.1.

Procedure. The procedure was the same as in Experiment 2.1 with the only difference being that all the stimuli (primes and targets) were presented in the bottom-to-top orientation. Before the start of the experiment, participants performed 8 practice trials.

2.5.2 Results

Latencies for incorrect responses were excluded (3.6% of the data), as were latencies that were shorter than 300 ms (0.2% of the data). The design of this experiment involved a single fixed effect, Prime Type, with two levels (TC vs. SC). The final statistical model for the latency data was: RT = glmer (RT ~ primetype + (1 |subject) + (1 |item), family = Gamma (link="identity"). In the error analysis, the final model was: Accuracy = glmer (accuracy ~ primetype + (1|subject) + (1|item), family = "binomial"). The other details were same as in Experiment 2.1. The mean RTs (in milliseconds) and percentage error rates for Experiment 2.4 are shown in Table 4 for the word targets.

Table 4: Mean Lexical Decision Latencies (RTs, in Milliseconds) and Percentage Error Rates for Words in Experiment 2.4

Condition	RT	%E
Transposed prime	869	2.9
Substitution prime	919	4.5
Priming	50	1.6

Note. The overall mean RT and error rate of the nonword targets were 1127 ms and 3.6% respectively.

Word trial latencies and accuracy. The 50-ms difference between the TC prime (869 ms) and the SC prime (919 ms) conditions was significant, ß = 25.788, *SE* = 3.379, *z* = 7.63, *p* < .001. The TC primes also led to significantly fewer errors (2.9%) than the SC primes (4.5%), ß = -0.257, *SE* = 0.099, *z* = -2.58, *p* = 0.01.

Nonword trial latencies and accuracy. In the latency data, there was a significant reverse main effect of Prime Type, with the SC primes (1108 ms) leading to faster latencies than the TC primes (1146 ms), ß = -18.148, *SE* = 6.362, *z* = -2.85, *p* = .004. There was no significant main effect of Prime Type in the accuracy analysis (*p* > .10).

2.5.3 Discussion

Although the stimuli in Experiment 2.4 were presented in an entirely novel orientation, participants still produced a clear TC priming effect which was essentially the same size as the TC priming effects in Experiment 2.1 and 2.2. This result once again provides support for the argument that these types of effects are much more consistent with an abstract letter/character unit account rather than in terms of a perceptual learning account.

2.6 General Discussion

Four masked priming experiments involving the presentation of stimuli in different orientations were carried out in order to investigate the role of text orientation in orthographic processing and to provide a basis for contrasting perceptual learning-based accounts of form priming in Chinese against accounts based on abstract letter/character units. The results of Experiment 2.1 were that repetition and TC priming effects were observed for stimuli presented in both horizontal and vertical orientations, paralleling Witzel et al.’s (2011) results. The only difference between experiments was that, unlike Witzel et al.’s Japanese readers whose performance was similar with horizontal and vertical words, the Chinese readers in Experiment 2.1 were considerably (72 ms) faster and their priming effects were slightly (12 ms), but not significantly, stronger with horizontal text than with vertical text, a pattern that would be consistent with either type of account. In Experiment 2.2, Chinese native readers showed masked repetition and TC priming effects when the text was presented in a right-to-left orientation. In Experiment 2.3, there again was strong repetition and, what can be considered, TC priming effects when left-to-right targets followed right-to-left primes. Finally, even though Experiment 2.4 involved an entirely new text orientation, participants produced a TC priming effect that was virtually the same size as those in Experiments 2.1 and 2.2, providing probably the clearest evidence against a perceptual learning account of our form priming effects.

More specifically, taken together, the finding of priming in all situations investigated and essentially equivalent priming in the repetition conditions and in the TC conditions in Experiments 2.1, 2.2 and 2.4 are inconsistent with Grainger and Holcomb’s (2009) special coordinate system account and Dehaene et al.’s (2005) LCD model. Rather, the processes which mediate these priming effects appear to occur at an abstract level of representation, in line with Witzel et al.’s (2011) abstract letter unit account. This account assumes that the orthographic code is created by transforming a visuospatial code into an ordinal code. Thus, regardless of the text orientation, what the reader takes as the beginning letter/character is assigned to the first position, and the next letter/character is assigned to the second position, and so on. Crucially, the presented text orientation is not directly related to this orthographic code, as readers appear to convert the visuospatial code into an abstract code quite rapidly and doing so may very well be required before lexical processing can advance.

Perhaps surprisingly, it was possible to expand this conclusion to the situation in which the prime, but not the target, was written right-to-left. What is also important to recognize is that these effects (and the TC priming effect with the bottom-to-top orientation) were demonstrated with Chinese four-character words. It’s not inevitable that such effects would be found with other scripts in other languages. In fact, in English, Guerrera and Forster (2008) found that, although there was a reasonably large priming effect when eight-letter targets contained all the letters of the prime but with only two of those eight letters in the same position in the prime and target, they failed to detect a priming effect with more extreme transposition primes, such as when edisklaw and isedawkl primed the target SIDEWALK. That is, their data support the idea that there is a limit to the amount of distortion in the ordering of letters/characters that the reading system can tolerate.

At mentioned above, there would appear to be one examination of the question of the system's ability to tolerate backwards primes and targets in the English language literature. Davis, Kim, and Forster (2008) presented backwards targets (e.g., ECAF), with each target preceded by either a forward prime (e. g., FACE) or a backward prime (e.g., ECAF). Although forward primes produced a facilitation effect, backward primes did not (in contrast to the results in Experiment 2.2), even though the targets were also presented in the backward direction. This result implies that there is a basic difference in the level of tolerance for position distortions in the orthographic code between Chinese and English readers, although it could also reflect a difference in how reverse spelling targets are processed in the two languages. The latencies, for example, in Davis et al. were approximately 200 ms longer than in the present Experiment 2.2 suggesting that Davis et al.'s subjects had considerably more difficulty dealing with right-to-left written words than the present subjects did.[4]

The question is, therefore, whether the backward priming effects observed here can be successfully accommodated within any of the current abstract letter/character accounts. That is, can any of those models mentioned previously actually explain the large priming effects from primes presented in noncanonical orientations (Experiments 2.2, 2.3 and 2.4)? At present, the answer would seem to be no. Most of those accounts do not currently have a mechanism for tolerating the level of distortion in terms of letter positions found in these primes and targets, which, of course, means that the null priming effect reported by Davis et al. (2008) is consistent with those models. The present results, in contrast, do raise problems for these models even though, in theory, they would all seem to have the ability to explain priming of this sort if the appropriate assumptions were made. Rather than expanding any of the models (by adding new assumptions) in an attempt to account for the present data, however, what seems to be a more fruitful approach would be to ask whether the present results might have arisen at a level other than the orthographic level. For example, as noted previously, one could propose that the effects may be morphemic or syllabic/phonological effects if it's reasonable to asssume that priming based on morphemic or syllabic/phonological relationships is capable of tolerating distortions in the ordering of that type of information.

More specifically, Chinese characters usually represent a single morpheme, and transposing morphemes will, most of the time, still maintain the morphemic relationship between the prime and target. There is a common consensus that processing morphologically complex words in English does require some type of morphemic processing (Crepaldi, Rastle, Coltheart, & Nickels, 2010; Crepaldi, Rastle, Davis, & Lupker, 2013; Drews & Zwitserlood, 1995; New, Brysbaert, Segui, Ferrand, & Rastle, 2004) and there is no reason to believe that similar conclusions would not apply to Chinese. Indeed, Zhang and Peng's (1992) Chinese word recognition model is based on the idea that there is a separate morpheme level involved in processing during word recognition. Supporting evidence for that conclusion includes Taft, Zhu, and Peng's (1999) demonstration that the latencies for transposable Chinese compound words (multiple morpheme words in which transposing the morphemes forms a different word) were longer in a lexical decision task than for nontransposable compound words. Taft et al. interpreted their results as suggesting that Chinese characters have position free representations, that is, that position information is highly flexible when processing character level representations, a conclusion that would be compatible with the present results.

Additional support for this idea comes from Wu, Tsang, Wong and Chen (2017) who showed that target words (e. g.,公園, city park) induced a similar P200 component when preceded by primes in which a shared character plays a similar morphemic role (e.g., 公眾, citizen) versus primes in which that same shared character in the prime and target does not (e.g., 公雞, rooster). However, an N400 component was only produced when the targets were preceded by morphemically related primes. The difference between these two prime types could not be due to a difference in orthographic similarity because the two primes share the same character with the target (e.g., 公, city), nor is it likely to have been due to semantics, because semantic primes not sharing a morpheme (e.g., 草地, lawn) produced only very small effects in both the behavioral and ERP data. This study suggests that morpheme level processing in Chinese does occur at an early stage of visual word recognition, consistent with models like the hybrid model (Diependaele, Sandra, & Grainger, 2009) and the Lemma model (Taft & Nguyen-Hoan, 2010). In the latter model, lemmas are immediately and unconsciously encoded once the morpho-orthographic decomposition has finished, prior to the whole word processing stage. The implication for the present data is that the unusual orientation priming effects for four-character Chinese words observed here could possibly have been morphemic effects if the morphemic processing system can tolerate the level of character transposition involved in the present experiments.

Alternatively, Chinese characters are also syllables and reversing their order changes only the order of the word’s phonology. Some studies have indicated that phonological priming effects do arise in Chinese which has led some researchers to suggest that the syllable is a functional unit in spoken word production in Chinese (Schiller, 1999; You, Zhang, & Verdonschot, 2012). For example, in You et al.’s (2012) examination of syllable priming effects during Chinese spoken word production, their results indicated that when primed by CV (密,/mi4/, dense) primes, CV targets (迷你,/mi2.ni3/, mini)) were named faster than when they were primed by CVN (N represents word endings involving n/or/ng/, e.g., 敏,/ min3/, agile), CVG (G represents word endings with glide sound, e.g., 卖,/ mai3/, sale) or unrelated primes (耍,/shua3/, play). Qu, Damian, and Li (2016) also found syllable facilitation priming effects in a picture naming task, whereas Zhou and Marslen-Wilson (2009) found mixed pseudohomophones (e. g., 严革,/ yan2ge2/) which retain one character in the same position as the target (e. g., 严格,/yan2ge2/, terrible) produced an inhibitory effect in comparison to control nonword primes. In contrast, however, Wong, Wu, and Chen (2014) showed no significant difference between a syllabic related prime condition and an unrelated prime condition (in either behavioral or ERP results), which caused them to argue that the role of phonology is limited during Chinese word recognition. Everything considered, it does appear that the answer to the question of whether the syllable is a functional unit in Chinese visual word processing is still not entirely clear and, therefore, whether (and how) shared syllables can produce inhibitory or facilitory priming is yet to be determined. In general, however, what should be noted is that the above studies do not rule out the possibility that the present priming effects from primes in different orientations may have had somewhat of a syllabic basis.

In this context, it is worth noting that Witzel et al. (2011) used Japanese kana words as their experimental stimuli. Each kana character is essentially a syllable. Therefore, one could also propose that what Witzel et al. have shown is a transposed syllable/phonological priming effect rather than an orthographically based TC priming effect. Potentially arguing against that idea are two papers showing that transposed phoneme nonwords are not effective primes in Japanese. That is, Perea and Pérez (2009) failed to find any masked transposed phoneme priming effects (a.re.mi.ka-a.me.ri.ka versus a.ma.ro.ka-a.me.ri.ka) with Japanese Kana words in two experiments. Further, Perea, Nakatani, and van Leeuwen (2011) found similar fixation times for transposed-consonant nonwords (a.re.mi.ka [アレミカ]–a.ri.me.ka [アリメカ]) versus orthographic control nonwords (a.ke.hi.ka [アケヒカ]–a.me.ri.ka [アメリカ]) in the periphery in an event boundary paradigm. A counter argument, however, is that there is good evidence that the mora (essentially a syllable) rather than the phoneme is the basic phonological unit in Japanese (e.g., Ida, Nakayama & Lupker, 2015). Therefore, it isn't clear what implications Perea and colleagues' lack of phoneme transposition effects would have for the character transposition effects reported by Witzel et al.

Nonetheless, as Grainger (2018) has argued, orthographic processing is the main interface between lower-level visual coding and higher-level linguistic processing in essentially all languages (Grainger, 2016; Grainger, Dufau, & Ziegler, 2016). Consistent with this idea, all of the models assuming a "relative-position-based" coding scheme also assume that letter identity and letter position coding occur during an early orthographic stage, with phonological processing occurring subsequently. As a result, no matter what the input language is, the implication is that orthographic processing should always dominate the visual word recognition process with morphemic and syllabic/phonological processing playing a secondary role. Hence, the default assumption would seem to be that the effects reported here are orthographically-based.

In summary, the present experiments showed significant repetition and TC priming effects in the text orientations investigated here (e.g., left-to-right horizontal, top-to-bottom, right-to-left horizontal and bottom-to-top orientations). These findings suggest that in a logographic script, the processes which mediate these form priming effects occur at an abstract level of representation, supporting Witzel et al.’s (2011) abstract letter unit account over any perceptual learning account. How models of orthographic coding can fully explain these results remains an issue for future model development. Before doing so, however, it would seem to be worthwhile to at least investigate the possibility that some of the priming effects observed here may not be orthographic but may be either morphemic or syllabic/phonological and, hence, would not need to be explained by models of orthographic coding.

2.7 Footnotes

[1] For the interested reader, I report the analyses of our nonword data for all of these experiments. However, as there was only one list of nonword primes and targets in each experiment (i.e., nonword targets were not counterblanced over conditions), the nonword results should be interpreted very cautiously.

[2] Following a suggestion of one of the Reviewers, I elected to use the generalized linear mixed-effects model and analyze raw RTs rather than following the more common practice of using linear mixed-effects models and normalizing raw RTs with a reciprocal transformation. The main reason for doing so was because nonlinear transformations systematically alter the pattern and size of interaction terms, casting doubt on the reliability of analyses of interactions. We did, however, replicate the analyses reported in the present paper using linear mixed-effect models with inverse-transformed RTs (invRT = 1000/RT) as the dependent variable. Those analyses replicated the pattern found with generalized linear mixed-effects models, with two exceptions, one of which is potentially notable, the interaction between Priming and Orientation in Experiment 1. To preview, the priming effect was 12 ms larger for the horizontal versus the vertical orientation words in Experiment 1. While this difference led to a significant interaction between Priming and Orientation in the linear mixed-effects model with transformed RTs, *ß* = -0.014, *SE* = 0.004, *t* = -3.874, *p* < .001, it did not in the generalized linear mixed-effects model with raw RTs. Traditional mean-based ANOVAs also failed to return a significant Priming by Orientation interaction in both the subject (*F*(1,39) = 3.10, *p* = .086) and item (*F*(1,191) = 2.39, *p* = .124) analyses, suggesting that the inverse transformation of RTs in the linear mixed-effects model might have artificially exaggerated the difference in priming across orientations. The second exception is the 16 ms difference between the classic TC prime condition and the repetition prime condition in Experiment 3. That contrast was not a central one in that experiment.

[3] In all analyses, when convergence warnings were returned, the troubleshooting process followed the recommendations made by the lme4 authors (see the “convergence” help page in R), including restarting the fit from the apparent optimum position and re-running the model with all available optimizers. The R syntax used to restart the model from the previous fit and re-run the model with all available optimizers is the following:

```
model.restart <- update(model, start= getME(model, c("theta","fixef")))

source(system.file("utils", "allFit.R", package="lme4"))

model.all <- allFit(model)
```

[4] Morris and Still (2012) also investigated backward prime priming effects in English. However, their experiment differs from Davis et al.'s (2008) and the current investigation in that their backward primes were themselves words (e.g., flow-WOLF) and that those primes produced an inhibitory, rather than a facilitory, effect. One could certainly imagine that, as Morris and Still suggest, their inhibition effect is a lexical competition phenomenon and, hence, it’s not clear to what extent Morris and Still’s results would be relevant to the results reported here.

Chapter 2.1 (Summary and Transition)

Chapter 2 has demonstrated that a) extreme TC priming effects exist in Chinese in situations whereas such extreme effects do not appear to exist in alphabetic languages (e.g., Guerrera & Forster, 2008) and b) these effects even exist when the text is presented in a novel orientation. The focus of Chapter 3 is addressing the first of these facts by gaining an understanding of the locus of the masked priming effect reported in Chapter 2 when Chinese L1 readers were responding to four-character Chinese words presented backwards (Experiment 2.3). That is, in Experiment 2.3, there was a sizeable priming effect when the primes were presented backwards and the targets were presented forwards (e.g., 同不所有(DCBA)-有所不同 (ABCD)).

The relatively clear difference between the nature of priming effects in English and Chinese does seem to imply that successful models of orthographic coding in English will not be able to explain the orthographic coding process in Chinese (and vice versa). Therefore, prior to considering the implication of all of the orthographic coding models seemingly being unable to explain this backwards priming effect in Chinese, an important question would be whether that effect actually is an orthographic coding effect or if it is due to processing at a higher level.

More specifically, as mentioned previously, Chinese characters are not only orthographic symbols, they are also morphemes and syllables. When the characters in a four-characer Chinese word are presented backwards, the result is a Chinese character string that still contains the same morphemes and syllables as in the original word, merely transposed (e.g., 突如其来(/tū rú qí lái/, suddenly)- 来其如突(/lái qí rú tū/)). As such, one could reasonably argue that any backward priming effects may arise at the morphemic/meaning or syllabic/phonological level. Certainly, there is clear evidence for (nontransposed) priming of both sorts in Roman letter languages (e.g., phonological - Berent, 1997; Crepaldi et al., 2010; Ferrand & Grainger, 1992; Grainger & Ferrand, 1994; Holyk & Pexman, 2004; morphological - Rastle & Davis, 2008; Rastle, Davis, & New, 2004). Further, although there appears to be no data on the question of transposed phonological priming, Crepaldi, Rastle, Davis and Lupker (2013) have demonstrated transposed morpheme priming in English.

Therefore, in order to understand the nature of backward priming effects with Chinese characters, one question that must be resolved is whether the extreme TC effects observed in Chinese truly are orthographic or whether they may have, to at least some extent, a morphemical/meaning or syllabic/phonological basis. In Chapter 3, I used two different paradigms (the masked priming same-difference task and masked lexical decision task) as well as two different script types (logographic scripts from Chinese and Japanese (Kanji); syllabic script from Japanese (Hiragana and Katakana)) in order to separate the impact of orthography from those of morphology and phonology.

Experiment 3.1 was designed to directly investigate the effects of backward syllabic/phonological priming. If the backward priming effect comes, at least partially, from syllabic/phonological information, then Chinese readers would respond faster following syllabically similar backwards primes than following syllabically unrelated primes. If no priming effect is observed in the syllabically backward condition, however, it indicates that the backward priming effect is either orthographically and/or morphologically/meaning based. Experiment 3.2 was intended to examine whether there is any contribution of syllabic/phonological information to priming of four-character Chinese target words at all (i.e., even when the syllabically related primes are presented in the forward direction).

As Experiments 3.1 and 3.2 provided a way to separate syllabic priming from orthographic and/or morphological priming, Experiments 3.3 and 3.4 were attempts to evaluate the contribution of priming based on morphological/meaning relationships. Experiment 3.3 and 3.4 involved a masked priming same-different task, a task that is based to a large degree on orthographic processing (Kinoshita & Norris, 2009; 2010; Norris & Kinoshita, 2008) and, most importantly, there is good evidence that priming in this task is not morphologically-based in either Spanish (Duñabeitia, Kinoshita, Carreiras, & Norris, 2011) or Hebrew (Kinoshita, Norris, & Siegelman, 2012). The goal of Experiment 3.3 was to deterimine whether the same was true in Chinese.

To that end, Gu et al.'s (2015) stimuli were used in Experiment 3.3. (I used two-character Chinese words here because it is nearly impossible create the relevant manipulation using fou-character Chinese words because there are no single-morpheme four-character Chinese words.) In Gu et al.'s experiment, two types of two-character Chinese words were used. One was two-morpheme words in which each character represented a morpheme. The other was single-morpheme words in which a single morpheme was created by combining the two characters in a specific order. Both types of words were used in a masked priming lexical decision task in which the primes were transpositions of the two characters. For the former type of words, the transposition of characters maintains the two morphemes in the word. For the latter type of words, the transposition of characters destroys the morpheme. What Gu et al. found was that the two word types showed equivalent priming effects, suggesting that the priming effects were not based on the preservation of morphemes (i.e., it was not a transposed morpheme effect). Finding the same pattern in the masked priming same-different task in Experiment 3.3 would support the idea that morphological priming does not play a role in that task in Chinese.

In Experiment 3.4, the stimuli from Experiment 3.1 that produced backward priming in a lexical decision task were then used in a masked priming same-different task. The question was whether they would produce the same size effect as was found in Experiment 3.1. If the size of the backward priming effect in the masked priming same-different task approximates that in the lexical decision task (Experiment 3.1), the most likely conclusion would be that the backward priming effect in Chinese is essentially an orthographic effect. If the priming effect is null (or small) in this task, however, a more appropriate conclusion would be that at least part of the priming effect is morphemically/maning-based.

Experiment 3.5 was another attempt to evaluate the potential morphological/meaning contribution to TC priming. I used the various script types in Japanese to create a situation in which the impact of morphological transpositions can be isolated from the impact of orthographic transpositions using both the logographic Kanji stimuli and the syllabic Katakana stimuli in a masked priming lexical decision task. If TC priming is not morphologically/meaning-based, there should be no extra priming due to the TC Kanji primes sharing morphemes with their targets, that is, no extra priming beyond that produced by orthographic (and possibly phonological) factors which can be documented by the TC priming effects with Katakana primes and targets.

Chapter 3

3 The Origins of Backward Priming Effects in Logographic Scripts for Four-Character Words

3.1 Introduction

The essential goal of the orthographic coding process is to determine both letter identity and letter position in the word being read. Failure to do so would mean that readers would not be able to distinguish between orthographically similar words like “fate” and “fake” or “abroad” and “aboard”. Orthographic processing itself is thought of as a middle level interface between lower level visual input and higher level linguistic processing (Grainger, 2018). In general, orthographic processing is assumed to operate at an abstract level (i.e., the existence of abstract mental representations enables different types of visual input, e.g., lowercase and uppercase letters, to access the same mental representations). Support for this position comes from a number of sources including masked priming lexical decision tasks which show that priming effects, for example, repetition priming effects, are the same size for word targets preceded by a same-case prime as by a different-case prime as by a mixed-case prime (e.g., TABLE-TABLE vs. table-TABLE vs tAbLe-TABLE; Perea, Jiménez, & Gómez, 2014; Perea, Vergara-Martínez, & Gómez, 2015). Both repetition and form (e.g., tafle-TABLE) priming effects also appear to be relatively independent of the presented text’s orientation (Perea et al., 2018; Witzel et al., 2011; Yang & Lupker, 2019).

In a masked priming lexical decision task (Forster & Davis, 1984), a forward mask is presented for 500 ms, followed by a brief prime presented for less than 70 ms and then a word or nonword target. The nature of the task effectively prevents participants from consciously recognizing the prime, minimizing the impact of any participant strategies on task performance. The typical result is that orthographically similar primes (e.g., repetition primes like “table” or transposed-letter (TL) primes like “talbe”) produce shorter target (e.g., TABLE) latencies than orthographically dissimilar primes (e.g., unrelated primes like “house” or “homse”).

A number of models have now been proposed in an attempt to describe the orthographic coding process, (e.g., Davis, 2010; Gómez, Ratcliff, & Perea, 2008; Grainger, Granier, Farioli, Van Assche, & Van Heuven, 2006; Norris & Kinoshita, 2012b; Norris, Kinoshita, & van Casteren, 2010; Schoonbaert & Grainger, 2004; Whitney & Marton, 2013; Whitney, 2001). One of the major challenges for these models has been explaining TL priming effects, that is, the fact that word targets preceded by TL nonword primes (e.g., talbe for TABLE) are more quickly processed than those preceded by substitution-letter (SL) nonword primes (i.e., nonwords created by substituting two new letters for the transposed letters, e.g., tafhe for TABLE, e.g., Perea & Lupker, 2003a, 2003b, 2004). The latency difference between the TL and SL priming conditions is referred to as the "TL priming effect".

The current set of orthographic coding models is generally divided into two types: the "noisy position" models and the "open-bigram" models. The "noisy position" models (Davis, 2010; Gómez et al., 2008; Norris & Kinoshita, 2012; Norris et al., 2010) assume that orthographic processing involves the activation of abstract letter units with the activation of those units reaching a fairly high level before the letter positions are determined. TL priming effects emerge because TL primes like talbe contain all the same letters as the target word TABLE, so the letter units activated by the TL nonword prime can activate the lexical representation for TABLE more fully than a SL nonword prime like tafhe which only shares three letters with the target word TABLE.

The other type of model, the "open-bigram" models (Grainger, Granier, Farioli, Van Assche, & Van Heuven, 2006; Grainger & Van Heuven, 2003; Schoonbaert & Grainger, 2004; Whitney & Marton, 2013; Whitney, 2001) proposes the existence of bigram units as an intermediate level of representation between abstract letter units and word units. The bigram units represent the ordered bigrams in the given letter string. For example, when reading the TL prime talbe, the open bigrams ta, tl, tb, te, al, ab, ae, lb, le, and be are activated following activation of the letter units. Most of the bigrams that are relevant to processing the target word TABLE are activated by the TL prime talbe which is not the case for SL primes like tafhe.

The contrast between these two types of models is not the focus in the present research. The focus is understanding the locus of a recently reported masked transposed character (TC) priming effect (Yang, Chen et al., 2019) for Chinese L1 readers. Yang, Chen et al. investigated the impact of visuospatial orientation on form priming effects (e.g., repetition and TC priming) in Chinese, using Chinese four-character primes and targets presented in multiple, varied orientations (e.g., left-to-right, top-to-bottom, right-to-left, bottom-to-top). In Experiment 1, primes and targets were presented in both left-to-right and top-to-bottom orientations. In Experiment 2 both the primes and targets were presented in a right-to-left ("backward") orientation. In Experiment 3, only the primes were presented backward, with the targets being presented in the standard left-to-right orientation. Experiment 4 involved primes and targets in a bottom-to-top orientation. Yang, Chen et al. found significant TC and repetition priming effects in all four experiments, a result that is quite consistent with abstract letter unit accounts such as that proposed by Witzel et al. (2011). What's core to the present investigation is the results in Yang, Chen et al.'s (2019) Experiment 3, in which there were sizeable TC and repetition priming effects even though the primes were presented backward and the targets were presented forward (e.g., 同不所有(DCBA)-有所不同(ABCD)).

Priming effects from somewhat extreme transposition primes have, in fact, been observed in alphabetic languages as well. For example, using English stimuli, Guerrera and Forster (2008), in a fairly extensive examination of the tolerance of the letter position coding process to letter transpositions in the prime, demonstrated a priming effect when a prime was created by maintaining the initial and final letters in eight-letter targets while the internal six letters were pairwise transposed (e.g., sdiwelak-SIDEWALK). However, Guerrera and Forster also showed that there are limits as they failed to obtain priming effects in more extreme transposition conditions, for example, when the prime was formed by pairwise transposing all eight letters in the target (isedawkl-SIDEWALK) or by reversing the order of both the first four and final four letters in the target (edisklaw-SIDEWALK). Further, and more central to the present investigation, Yang, Jared, Perea and Lupker (2019) reported that four and five letter English words were not effective primes when the primes were those words written backward. These types of results, contrasted with Yang, Chen et al.'s (2019) results, imply that the process of coding letter positions during orthographic processing is considerably different for English readers (readers reading an alphabetic script) vs. Chinese readers (readers reading a logographic script).

At the very least, this relatively clear empirical difference between the nature of transposed letter/character priming effects in English and Chinese seems to imply that successful models of orthographic coding in English will have considerable difficulty explaining the orthographic coding process in Chinese (and vice versa). For example, most versions of the open-bigram models would not predict the activation of reversed bigrams such as ta and ab by a backward prime like elbat, hence preventing those models from predicting priming of forward targets (e.g., TABLE) by backward primes. The noisy position models are a bit more flexible in terms of what they could predict. That is, the degree to which they would allow TABLE to be activated by a backward prime like elbat is determined by the assumptions made concerning the values of various system parameters. The values used in the present versions of the models, however, are values that allow the models to predict null effects of the sort reported by Guerrera and Forster (2008) in English. Therefore, those values would not allow those models to predict virtually any priming from fully backward primes. As such, the backward priming effect in Chinese would seem to pose a serious challenge to the orthographic coding models developed for alphabetic languages.

As Gu, Li, & Liversedge (2015) note, “To date, no formal models of character position encoding have been developed for Chinese reading” (p. 135). However, in line with the immediately preceding discussion, Gu et al. also suggested, when discussing their own demonstration of TC effects for Chinese words, that models such as Taft and Zhu’s (1997a) multilevel activation model (see also, Taft, Zhu & Peng, 1999) could be extended in a way that would allow them to account for more extreme TC priming effects in Chinese. More specifically, it may be possible, within the framework of those models, to incorporate a noisy position-type orthographic coding process, such as that in Davis’s (2010) spatial-coding model. One could then tweak the parameters of that process in order to make the system considerably more tolerant of noise in position coding than the level of tolerance assumed when modeling reading in alphabetic languages.

Prior to considering the implication of the Chinese results for orthographic coding models developed for alphabetic languages, however, an important question to be considered is whether the Chinese priming effects actually are orthographic coding effects or whether they at least partially reflect priming from another source. More specifically, Chinese characters, unlike letters in alphabetic scripts, are not only orthographic symbols, they are also syllables and, often, morphemes. Therefore, when the characters in a four-characer Chinese word are presented backward, the result is typically a Chinese character string that contains the same sound and meaning units as in the original word, merely fully transposed (e.g., 突如其来(/tū rú qí lái/, suddenly) - 来其如突(/lái qí rú tū/)). As such, one could speculate that Yang, Chen et al.'s (2019) backward priming effect is not wholly orthographic as at least a portion of the effect may be driven by processing/representations at either the meaning or phonological processing levels, levels that can contribute to the priming process in a lexical decision task through some sort of feedback process. That is, the argument could be made that Yang, Chen et al.'s effect had multiple components which combined in some, presumably interactive, fashion.

In order for there to be either phonological or meaning-based masked priming in any task, two things need to be true. First, the brief prime needs to activate the relevant information and, second, that information needs to be relevant to target processing in the task at hand (i.e., it needs to impact the processing structures required to complete that task). At a theoretical level, both of these things could be true in any word recognition model that: a) that contains both phonological and meaning-based representations and b) is based on interactive-activation principles (i.e., one that allows activation to spread among units). Hence, any model of that sort would have the potential to explain those types of priming effects. At an empirical level, there is certainly evidence that both of these things are true for both types of priming in lexical decision tasks in alphabetic languages. That is, there is both masked phonological priming (Berent, 1997; Ferrand & Grainger, 1992, 1993; Grainger & Ferrand, 1994; Holyk & Pexman, 2004; see Rastle & Brysbaert, 2006, for a review) and masked meaning-based priming in that task (see Van den Bussche, Van den Noortgate, & Reynvoet, 2009).

With respect to these issues for Chinese readers, it is generally argued that phonological processing is quite slow when reading in logographic scripts, suggesting that phonological codes may not even be activated by a brief prime. Indeed, in some models of the process (e.g., Li, Rayner, & Cave, 2009), phonology is presumed to be activated so slowly that it would play no role in the reading process in general. In contrast, other interactive-activation models, such as Taft et al.'s (1999) which postulates direct linkages between phonological units and character units, do not make that assumption. Hence, models of that sort would, at least, allow for phonological priming. Therefore, the question of whether such units might contribute, in a feedback fashion, to the activation of the processing structures central to any given task would seem to be an empirical one.

Indeed, empirical examinations of the impact of masked primes in Chinese do indicate that such primes are able to rapidly activate phonological information (in contrast to Li et al.'s (2009) model's assumption), allowing them to produce priming effects at least when phonological information is relevant to the task at hand. That is, phonological priming has been observed for single character Chinese word targets in masked priming naming tasks (Perfetti & Tan, 1998; Perfetti & Zhang, 1995; Zhou & Marslen-Wilson, 1999). Further, Lupker, Nakayama and Yoshihara (2018) and Yang, Yoshihara, Nakayama and Lupker (submitted) have also shown that it is even possible to obtain phonological priming effects in logographic script experiments (using Japanese Kanji and Chinese) when the task itself does not require the activation of phonological information (i.e., in a masked priming same-different task). However, the question of whether such activation plays a role in making a lexical decision in Chinese is less clear, as neither Shen and Forster (1999) nor Zhou and Marslen-Wilson (2009) were able to find masked phonological priming effects in that task (even though they were using forward primes). Note, however, that in none of the relevant lexical decision experiments were the targets as long and as difficult to process as those used by Yang, Chen et al. (2019). Therefore, the possibility that there was at least a contribution of phonology to Yang, Chen et al.'s backward priming effect, along with the implications of that conclusion for orthographic coding models, needs to be considered and evaluated empirically.

The *a priori* case for a meaning-based contribution to Yang, Chen et al.'s (2019) backward priming effect would seem to be a bit more substantial. To begin with, at a logical level, because each character is assumed to be asssociated with a unit of meaning and, hence, character representations may be linked directly to meaning-level representations, the activation of such representations would seem to be quite efficient. Certainly, activation of meaning-based information would seem to be much more efficient in a logographic language like Chinese than in alphabetic languages in which the activation of meaning representations cannot be driven by individual letters. This type of idea is represented in Zhang and Peng's (1992) Chinese word recognition model which assumes a separate morphemic processing level. Hence, that model could explain the backward priming effect as being at least partially due to activation in those morphological units under the assumption that those units are relevant to the lexical decision making process.

In contrast, Taft, Liu and Zhu's (1999) multilevel interactive-activation framework of Chinese word processing does not propose specific morphemic processing units. Rather, the characters are assumed to activate relevant semantic units that are combined with the semantic units activated by other characters to produce a word's meaning. That meaning may or may not be somewhat different from that which would be produced by the sum of the individual character meanings (when read either backward or forward). Nonetheless, because in many instances the individual character meanings are going to be at least somewhat related to the full meaning of our four-character Chinese words, Taft Liu and Zhu's proposal would not necessarily be inconsistent with the discovery of a meaning-based component in Yang, Chen et al.'s (2019) backward priming effect.

Empirically, there are several studies using Chinese compound words indicating that meaning-based information is activated early in word recognition and affects processing in a lexical decision task (Zhang & Peng, 1992; Zhou & Marslen-Wilson, 1994, 1995; Zhou, Marslen-Wilson, Taft, & Shu, 1999). For example, both word and morpheme frequencies affect performance for both visual (Zhang & Peng, 1992) and auditory targets (Zhou & Marslen-Wilson, 1994). Other studies have shown that targets are processed faster when preceded by a shared-morpheme prime than by a unrelated prime in both visual lexical decision experiments (Zhou et al., 1999) and auditory lexical decision experiments (Zhou & Marslen-Wilson, 1995). Therefore, the possibilty that there was at least a contribution of meaning-based information to Yang, Chen et al.'s backward priming effect, along with the implications of that conclusion for orthographic coding models, needs to be considered and evaluated empirically.

One final issue needs to be mentioned. The question addressed in the present experiments, is not just whether phonological or meaning-based information activated by a masked prime could have contributed to Yang, Chen et al.'s (2019) effect but whether that information could have done so even though it was presented backward. Empirically, the question of the existence of backward or even transposed letter/character phonological priming does not appear to have been addressed in any language. At a theoretical level, however, any model that would allow for phonological priming in general and does not assume strict position coding of activated phonology (e.g., Taft, Zhu, et al., 1999) would also allow for backward phonological priming. In contrast, at least in English, an empirical demonstration of transposed morphological priming has been provided. That is, Crepaldi, Rastle, Davis and Lupker (2013) have demonstrated transposed morphological priming showing that position coding of meaning information is, like the position coding of orthographic informantion, somewhat flexible (see also Rastle & Davis, 2008; Rastle et al., 2004).

The present research was an attempt to address these issues. Experiment 1 was designed to directly investigate the effect of backward syllabic/phonological priming and to contrast that effect with the backward priming effect initially reported by Yang, Chen et al. (2019). The backward syllabic/phonological primes were created by using alternative Chinese characters that are homophonic with the characters in the targets (e.g., 佟步锁友 (tóng bù suǒ yǒu) - 有所不同(yǒu suǒ bù tóng)). Also included in Experiment 3.1 were primes that contained the same characters as the target but the characters were presented backward. This manipulation allowed us to attempt a replication of Yang, Chen et al.’s crucial result. The task was a masked priming lexical decision task. Based on Yang, Chen et al.’s results, one would expect to again obtain a significant backward priming effect (i.e., targets following backward primes would be processed faster than targets following backward unrelated primes). More importantly, if the backward priming effect comes, at least partially, from syllabic/phonological information, Chinese readers would respond faster following syllabically related backward primes than following syllabically unrelated primes. If no priming effect is observed in the syllabically backward condition, the implication would be that the backward priming effect is either orthographically- and/or meaning-based.

To look ahead, the syllabically-related backward primes produced no priming in Experiment 3.1. Therefore, Experiment 3.2 was carried out to examine whether there is any contribution of syllabic/phonological information to priming of four-character Chinese target words in a lexical decision task at all (i.e., when the syllabically-related primes are presented in the forward direction). If not, the clear implication is that prime-target syllabic/phonological relationships must have played virtually no role in producing Yang, Chen et al.'s (2019) effect.

Experiments 3.3, 3.4 and 3.5 represented an attempt to evaluate the potential contribution of meaning-based priming to Yang, Chen et al.'s (2019) backward priming effect. Both Experiments 3.3 and 3.4 involved a masked priming same-different task. The masked priming same-different task involves the initial presentation of a reference stimulus, followed by a brief masked prime (e.g., 50 ms) and then a visible target. The task is to indicate whether the reference stimulus and target are the same. The typical result is a large priming effect from orthographically similar primes on trials when the reference stimulus and the target are the same. Norris, Kinoshita and colleagues (Kinoshita & Norris, 2009, 2010; Norris & Kinoshita, 2008) have argued that priming in the same-different task is based entirely on processing at orthographic level, although that conclusion appears to be a bit strong as Lupker, Nakayama and colleagues have shown that this task is also at least somewhat sensitive to phonological information (Lupker, Nakayama, & Perea, 2015; Lupker et al., 2018).

Importantly, there is good evidence that priming in this task is not morphologically-based in either Spanish (Duñabeitia, Kinoshita, Carreiras, & Norris, 2011) or Hebrew (Kinoshita, Norris, & Siegelman, 2012). The goal of Experiment 3.3 was to deterimine whether the same was true in Chinese. To that end, Gu et al.'s (2015) stimuli were used. In Gu et al.'s experiment, two types of two-character Chinese words were used. One was two-morpheme words in which each character represented a morpheme. The other was single-morpheme words in which a single morpheme was created by combining the two characters in a specific order. Both types of words were used in a masked priming lexical decision task in which the primes were transpositions of the two characters. For the former type of words, the transposition of characters maintains the two morphemes in the word. For the latter type of words, the transposition of characters destroys the morpheme. What Gu et al. found was the two word types showed equivalent priming effects, suggesting that the priming effects were not based on the preservation of morphemes (i.e., it was not a transposed morpheme effect).

Finding the same pattern in the masked priming same-different task in Experiment 3.3 would support the idea that morphological/meaning-based priming does not play a role in that task in Chinese.

To again look ahead, the results of Experiment 3.3 indicated that, as in Spanish and Hebrew, morphological priming does not seem to play a role in the masked priming same-different task in Chinese. Based on this result, Experiment 3.4 was an attempt to assess the possibility that Yang, Chen et al.'s (2019) backward priming effect with four-character words has a morphological/meaning-based component. In Experiment 3.4, the stimuli from Experiment 3.1 that produced backward priming in a lexical decision task were used in a masked priming same-different task. The question was whether they would produce the same size effect as was found in Experiment 3.1. As it appears that morphological priming (at least backward morphological priming) does not play a role in the same-different task in Chinese, a finding of equivalent size priming effects in Experiments 3.1 and 3.4 would be expected. A null (or small) priming effect in Experiment 3.4 would be more consistent with the idea that at least part of the effect in Experiment 3.1 was meaning-based.

To again look ahead, similar size priming effects were found in Experiments 3.1 and 3.4, suggesting that the backward priming effects obtained for Chinese readers processing four-character targets are almost entirely orthographically-based. One could argue, however, that it can be a bit problematic to make cross-experimental paradigm comparisons because the processing mechanisms underlying the two experimental paradigms might be somewhat different. Therefore, Experiment 3.5 was another attempt to evaluate the potential morphological/meaning-based contribution to backward priming.

Unfortunately, it doesn't appear to be possible to disentangle morphological/meaning-based and orthographic effects using four-character Chinese stimuli. However, Japanese does provide such an option in that it allows the use of a mixture of the Kanji, Katakana and Hiragana scripts. Kanji is a logographic script which was originally derived from Chinese script. Although the two scripts are not identical, they do share many characters and, more importantly, as with Chinese characters, each Kanji character represents a morpheme, a syllable and an orthographic unit. Katakana and Hiragana, in contrast, are both syllabic scripts. Each character only provides syllabic/phonological and orthographic information (i.e., no morphological/meaning-based information). As will be described in the Introduction to Experiment 3.5, in that experiment we used these various script types to create a situation in which the impact of morphological/meaning-based transpositions could be isolated from the impact of phonological as well as orthographic transpositions by using both logographic Kanji stimuli and syllabic Katakana stimuli in a masked priming lexical decision task. The idea was that if TC priming is not meaning-based, there should be no extra priming due to the TC Kanji primes sharing morphemes with their targets, that is, no extra priming beyond that produced by orthographic and phonological factors which can be documented by the TC priming effects with Katakana primes and targets.

3.2 Experiment 3.1

3.2.1 Method

Participants. Thirty-two undergraduate students from Western University participated in this experiment. They all received course credit for their participation, were native speakers of Chinese, indicated that they were highly proficient in reading Simplified Chinese and had normal or corrected-to-normal vision with no reading disorder. A paper consent form was obtained from all of the participants before the start of all of the reported experiments.

Materials. Two hundred and forty four-character simplified Chinese words were chosen as the target words. Most of those words were selected from the *SUBTLEX-CH* database (Cai & Brysbaert, 2010). Most of the nonword stimuli were selected from among the nonwords listed in the Chinese Lexicon Project (Tse et al., 2017). The mean word frequency (per million) of these target words in the *SUBTLEX-CH* database (Cai & Brysbaert, 2010) is 1.63 (range: 0.03-48.5).

I created four different types of nonword primes for each word target, (1) syllabically related backward primes; (2) syllabically unrelated backward primes; (3) backward primes; and (4) backward unrelated primes. Syllabically related backward primes (e.g., 佟步锁友 (tóng bù suǒ yǒu)-有所不同(yǒu suǒ bù tóng)) are primes that have the same phonology as the targets, except in the right-to-left direction, while at the same time not sharing any characters (and, hence, any morphemes) with the target (as shown in the above example). The syllabically unrelated primes had no phonological overlap with their targets although the syllables of these primes produce a meaningful word when produced in the reverse order (e.g., 探话养咿 (tàn huà yǎng yī)-有所不同 (yǒu suǒ bù tóng)). Backward primes have all the same characters as the targets, however, the characters in the primes are presented in the right-to-left orientation (e.g., 同不所有(tóng bù suǒ yǒu)-有所不同 (yǒu suǒ bù tóng)). Backward unrelated primes are nonwords created by presenting the characters in an unrelated word in the right-to-left orientation (e.g., 碳化氧一(tàn huà yǎng yī)-有所不同 (yǒu suǒ bù tóng)).

The word targets were divided into 4 counterbalanced lists, each list containing 60 stimuli in each condition. Each participant only saw each word (and nonword) target once and each list was presented to ¼ of the participants. Another 240 four-character simplified Chinese nonwords were chosen as nonword targets. Three different types of primes were created for the nonword targets, (1) syllabically backward primes; (2) backward primes; and (3) unrelated primes. The backward and syllabically backward primes for the nonword targets were set up in a similar way as that for the word targets, but only one type of unrelated prime was used. One-half of the targets (120) was primed by unrelated primes and one-quarter of the targets (60) was primed by each of the other two prime types. However, only one list of primes and nonword targets was created. The primes and targets used different font styles and sizes (35-point Boldface font for the primes and 40-point Song font for the targets). The raw data used for the analyses and word stimuli used in all different experiments can be found at https://osf.io/vrp5d/.

Procedure. The participants were seated in a quiet room for testing. Data collection was accomplished using E-prime 2.0 software (Psychology Software Tools, Pittsburgh, PA; see Schneider, Eschman, & Zuccolotto (2002)). The stimuli were presented on a 19-inch CRT monitor using a refresh rate of 60HZ (16.67ms). The screen resolution was 1280 x 960. The background color was black and the stimulus color was white. The sequence of each trial was: a row of six hash masks (######) was presented for 500 ms, the prime followed for 50 ms, and then the target for 3000 ms or until the participant responded. All the stimuli were presented centrally. Participants were asked to decide whether each presented character string is a meaningful Chinese word or not. They were instructed to press the “J” button if the presented character string is a meaningful Chinese word and the “F” button if it is a nonword. They were asked to respond as quickly and as accurately as possible. Stimulus presentation was randomized for each subject. The experimental block included 480 trials in total, 240 word trials and 240 nonword trials. Participants received eight practice trials before starting the experimental block. This research was approved by the Western University REB (Protocol # 108835).

3.2.2 Results

Data for the word target “自不量力” were removed because it was presented twice to each participant. Four additional word targets were also excluded from the data analysis due to the fact that they produced error rates higher than 40%. Response latencies less than 300 ms (0.1% of the data), more than 3 standard deviations from the participant’s mean latency trials (5.4% of the data) and from incorrect trials (2.1% of the data) were excluded from the latency analyses. The data from nonword targets were not analyzed due to the fact that the nonword targets were not counterbalanced across prime type. Generalized Linear mixed-effects models from the lme4 package were used to analyze the latency and error rate data (Bates et al., 2015; Lo & Andrews, 2015; “R Core Team,” 2015). For word targets, subjects and items were treated as random effects. Prime Type (syllabic vs. backward) and Relatedness (related vs. unrelated) were treated as fixed effects (Baayen, 2008; Baayen et al., 2008). The emmeans package was used for post-hoc analyses (R V Lenth, 2018). Before running the model, R-default treatment contrasts were altered to sum-to-zero contrasts (Levy, 2014; Singmann & Kellen, 2018). For the latency analysis of word targets, the model was: RT = glmer (RT ~ Prime Type * Relatedness + (Relatedness|subject) + (Relatedness|item), family = Gamma(link="identity"), control = glmerControl(optimizer = "bobyqa", optCtrl = list (maxfun=1e6))). For the error rate analysis of word targets, the model was: Accuracy = glmer (accuracy ~ Prime Type * Relatedness + (Relatedness |subject) + (Relatedness |item), family = "binomial", control = glmerControl(optimizer = "bobyqa", optCtrl = list (maxfun=1e6))), both models converged after a restart. More complex models which included all relevant random structures were used in our initial analyses but, ultimately, I had to use the models noted above due to convergence failures with the more complex random slope models (Barr, 2013). The mean RTs and percentage error rates from a subject-based analysis for the word targets are shown in Table 5. My method for determining the appropriate level of power in each of the experiments was based on Brysbaert and Stevens's (2018) suggestion that there should be at least 1600 trials in each condition.

Table 5: Mean Lexical Decision Latencies (RTs, in Milliseconds) and Percentage Error Rates for Words in Experiment 3.1

	Syllabic condition		Backward condition	
	RT	%E	RT	%E
Related	719	6.4	660	3.5
Control	724	6.7	714	5.7
Priming	5	0.3	54	2.2

Note. RT= reaction time; %E=percentage error rate. The overall mean RT and error rate for the nonword targets were 914 ms and 7.1% respectively.

In the latency data, the main effect of Prime Type was significant, ß = 17.475, *SE* = 1.644, $z = 10.63$, $p < .001$, and there was also a significant main effect of Relatedness, ß = -15.943, *SE* = 3.775, $z = -4.22$, $p < .001$. Responses were faster overall in the backward conditions and for related primes. The interaction between Prime Type and Relatedness was also significant, ß = 12.707, *SE* = 1.581, $z = 8.04$, $p < .001$, with the backward priming effect (54 ms) being significantly larger than the backward syllabic priming effect (5 ms). In the post-hoc analyses (which are actually planned comparisons), the 5 ms backward syllabic priming effect was not significant, ß = -6.47, *SE* = 8.10, $z = -0.80$, $p = .424$, however, there was a highly significant backward priming effect, ß = -57.30, *SE* = 8.27, $z = -6.93$, $p < .001$.

In the error rate analysis, the main effect of Prime Type was significant, ß = -0.225, *SE* = 0.052, $z = -4.37$, $p < .001$, with slightly more errors in the syllabic conditions (6.5%) than in the backward conditions (4.6%). There was also a main effect of Relatedness, ß = 0.171, *SE* = 0.08, $z = 2.13$, $p = .033$, with slightly more errors in the unrelated conditions (6.2%) than in the related conditions (5.0%). More importantly, the interaction between these two factors was significant, ß = -0.126, *SE* = 0.052, $z = -2.43$, $p = .015$. In the post-hoc analyses, targets following backward related primes elicited fewer errors (3.5%) than targets following backward unrelated primes (5.7%), ß = 0.593, *SE* = 0.204, $z = 2.91$, $p = .004$. In the syllabic conditions, the error rate was similar for targets following backward syllabically related (6.4%) vs backward syllabically unrelated primes (6.7%), $ß = 0.089$, $SE = 0.177$, $z = 0.50$, $p = .616$.

I further conducted a Bayes Factor analysis in order to quantify the statistical evidence supporting the Prime Type by Relatedness interaction. The Bayes factor analysis was calculated using the Bayesian Information Criterion (BIC) approximation of the Bayes Factor (Wagenmakers, 2007). In all of these experiments where this analysis was used, the Bayes Factor BF_{01} was calculated using the BIC values for the model without the interaction (the null hypothesis H_0) and for the model with the interaction (the alternative hypothesis H_1), using the formula $BF_{01} = \exp((\mathrm{BIC}(H_1) – \mathrm{BIC}(H_0))/2)$ (Wagenmakers, 2007, p. 796). A BF_{01} less than 1 would suggest evidence in support of H_1 (i.e., the alternative hypothesis), whereas BF_{01} greater than 1 would suggest evidence in support of H_0 (i.e., the null hypothesis) and $BF_{01} = 1$ would suggest equivalent evidence for the two hypotheses. I used Jeffreys's (1961) classification scheme to help interpret the results of Bayes Factor analysis. In Experiment 3.1, The Bayes Factor, $BF_{01} < 0.001$, in Jeffreys's classification scheme, indicates "strong" evidence for the alternative hypothesis, the hypothesis that there is an interaction between the two factors.

In order to more closely examine the 5 ms null effect of in the syllabic condition, I re-ran the model using the data for just that condition using only Relatedness as a factor. The Bayes Factor BF_{01} was calculated using the BIC values for the model with no effect (the null hypothesis H_0) and for the model with an effect of Relatedness (the alternative hypothesis H_1). The other details are the same as described previously. In this analysis, the Bayes Factor was $BF_{01} = 43.76$, indicating "strong" evidence for the absence of a relatedness effect.

3.2.3 Discussion

The results of Experiment 3.1 show that there was no significant syllabic backward priming effect while at the same time replicating the overall backward priming effect reported by Yang, Chen et al. (2019). This pattern strongly suggests that syllabic information presented in a backward direction provides no priming and, therefore, that the backward priming effect must come from the contribution of orthography and/or meaning. Potentially, this conclusion may seem a bit surprising as a few studies (e.g., Perfetti & Tan, 1998) have suggested that masked primes do rapidly activate phonological information in Chinese (although see, for example, Chen, Hsuan-Chih, & Shu, 2001). Therefore, in Experiment 3.2, the issue of phonological priming for four-character Chinese words in a lexical decision task was examined in a slightly different way, by determining whether it would be possible to observe syllabic/phonological priming with four-character Chinese primes and targets when both were presented in the standard left-to-right direction (e.g.,有所不同(yǒu suǒ bù tóng)). If there is no syllabic/phonological priming in Experiment 3.2, the clear implication is that Yang, Chen et al.'s backward priming effect for four- character Chinese words in a lexical decision task does not have a phonological component.

3.3 Experiment 3.2

3.3.1 Method

Participants. Sixty undergraduate students from Western University participated in this experiment. All received course credit for their participation, were native speakers of Chinese, indicated that they were highly proficient in reading Simplified Chinese and had normal or corrected-to-normal vision with no reading disorder.

Materials. Ninety four-character simplified Chinese target words (and their nonword primes) were used in this experiment. Eighty-nine of them had been used in Experiment 3.1 with the one new target and its primes being created as a replacement for the duplicated target in Experiment 3.1. The mean word frequency (per million) of target words in the *SUBTLEX-CH* database (Cai & Brysbaert, 2010) is 3.38 (range: 1.28-48.5). More importantly, only syllabic priming was investigated and, therefore, only two different types of primes for each word target were used in Experiment 3.2. These were the same primes as used in Experiment 3.1, (1) syllabically related primes presented forward (e.g., 友琐布佟 (yǒu suǒ bù tóng)-有所不同(yǒu suǒ bù tóng)) and (2) syllabically unrelated word primes presented forward (e.g., 升勿穴痂 (shēng wù xué jiā)-有所不同 (yǒu suǒ bù tóng)).

The counterbalancing procedure was slightly different than in Experiment 3.1. In order to create the desired counterbalancing, the word targets were divided into 3 lists with 30 stimuli in each list. Two of those lists of targets were presented to each participant (with the lists being rotated across participants in order to complete the counterbalancing). The specific goal of using this counterbalancing procedure was to create unrelated prime-target pairs using only the primes from other targets in the experiment while, at the same time, not having the related targets for those unrelated primes also being presented to a given participant. Therefore, for each participant, each of the 30 targets in the unrelated condition was primed by one of the primes from the 30 targets not used for that participant.

Sixty of the four-character simplified Chinese target nonwords (and their primes) used in Experiment 3.1 were used in Experiment 3.2. The same manipulation that was used for the word targets was used for the nonword targets (i.e., the four-character nonword targets were preceded either by a syllabically related prime or a syllabically unrelated prime). Only one list of primes and nonword targets was created with 30 stimuli in each condition. The other details were the same as in Experiment 3.1.

Procedure. The procedure was the same as in Experiment 3.1, except that all the primes were presented forward. The experimental block included 120 trials in total, 60 word trials and 60 nonword trials. Participants received eight practice trials before beginning the experimental block.

3.3.2 Results

Response latencies less than 300 ms (0.1% of the data), more than 3 standard deviations from the participant's mean latency (1.9% of the data) and from incorrect trials (3.4% of the data) were excluded from the latency analyses. Only one single fixed effect was involved in this experiment, Relatedness, with two levels (syllabically related vs. syllabically unrelated). The final statistical model for the latency data was: RT = glmer (RT ~ Relatedness + (Relatedness |subject) + (Relatedness |item), family = Gamma (link="identity"), control = glmerControl (optimizer = "bobyqa", optCtrl = list (maxfun=1e6))). In the error analysis, the final model was: Accuracy = glmer (accuracy ~ Relatedness + (Relatedness |subject) + (Relatedness |item), family = "binomial"). The other details were same as in Experiment 1. The mean RTs (in ms) and percentage error rates for Experiment 3.2 are shown in Table 6 for the word targets.

Table 6: Mean Lexical Decision Latencies (RTs, in Milliseconds) and Percentage Error Rates for Words in Experiment 3.2

Condition	RT	%E
Syllabic related prime	695	3.4
Syllabic unrelated prime	697	3.6
Priming	2	0.2

Note. RT= reaction time; %E=percentage error rate. The overall mean RT and error rate of the nonword targets were 905 ms and 6.2% respectively.

The 2 ms difference between the related prime (695 ms) and the unrelated prime (697 ms) conditions was not significant in the latency analysis, *ß* = -1.310, *SE* = 4.389, *z* = -0.30, *p* = .765; nor was the 0.2% difference significant in the error rate analysis, *ß* = -0.291, *SE* = 0.203, *z* = -1.43, *p* = .152.

A Bayes Factor analysis was conducted to evaluate the statistical evidence for the null effect. The Bayes Factor BF_{01} was calculated using the BIC values for the model with no effect (the null hypothesis H_0) versus a Relatedness effect (the alternative hypothesis H_1). The other details are the same as in Experiment 3.1. In Experiment 3.2, The Bayes Factor, BF_{01} = 56.19, in Jeffreys's (1961) classification scheme, indicates "strong" evidence for the absence of a Relatedness effect.

I also contrasted the backward syllabic priming effect in Experiment 3.1 with the forward syllabic priming effect in Experiment 3.2. Orientation (backward vs. forward) and Relatedness (related vs. unrelated) were treated as fixed effects (Baayen, 2008; Baayen et al., 2008). The final GLMM analysis model used here for the latency data was: RT = glmer (RT ~ Relatedness*Orientation + (Relatedness|subject) + (Relatedness|item), family = Gamma (link="identity"), control = glmerControl(optimizer = "bobyqa", optCtrl = list (maxfun=1e6))). In the error analysis, the final model was: Accuracy = glmer (accuracy ~ Relatedness*Orientation + (Relatedness|subject) + (Relatedness|item), family = "binomial", control = glmerControl(optimizer = "bobyqa", optCtrl = list (maxfun=1e6))). In the latency data, none of the main effects or the interaction approached significance (all *ps* > 0.1). In the error rate analysis, only the main effect of Orientation was significant, $ß = -0.335$, $SE = 0.122$, $z = -2.75$, $p = .006$, with more errors produced using primes in the backward orientation than in the forward orientation.

3.3.3 Discussion

The results of Experiment 3.2 produced virtually no evidence for syllabic/phonological priming for four-character Chinese words even though the prime characters were presented in the standard left-to-right orientation. These results further support the conclusion based on the data from Experiment 3.1 that Yang, Chen et al.'s (2019) backward priming effect does not have a syllabic/phonological component. That is not to say, of course, that phonology was not activated by the primes in Experiment 3.2, rather what appears to be the case is that the processes involved in making a lexical decision in Chinese, even with four-character stimuli are not impacted by prime-activated phonology.

Experiments 3.3, 3.4 and 3.5 were attempts to evaluate the question of whether the backward priming effect might have a morphological component. Unfortunately, due to the nature of Chinese, it is not possible to create four-character stimuli that would allow us to separate orthography from morphology. That is, it is not possible to create primes that share one of these attributes but not the other with their targets. Experiments 3.3 and 3.4, however, adopt a slightly different approach to trying to answer this question, one involving a change in the experimental task.

3.4 Experiment 3.3

In Experiments 3.3 and 3.4, the task used was the masked priming same-different task. Priming in this task appears to be orthographically-based in English (Kinoshita & Norris, 2009, 2010; Norris & Kinoshita, 2008), although, as noted, there is evidence that phonology can have some impact as well (Lupker, Nakayama, et al., 2015; Lupker et al., 2018; Lupker, Perea, et al., 2015). More importantly, there is clear evidence that priming in the same-different task has no morphological component in the languages in which that issue has been evaluated, Spanish (Duñabeitia, Kinoshita, Carreiras, & Norris, 2011) and Hebrew (Kinoshita, Norris, & Siegelman, 2012).[1] At this point, however, there are no demonstrations that such is the case in Chinese.

Experiment 3.3 was an attempt to examine this issue in Chinese, using a manipulation reported by Gu et al. (2015). What those authors did was to investigate morphological priming in a masked priming lexical decision task using a transposed character priming procedure. They used two-character Chinese words as targets and their manipulation involved two word types. In one word type, the two characters each represented a morpheme. Hence, when the characters were transposed, the two morphemes remained intact. The other words were monomorphemic. Therefore, when the characters in those words were transposed, the morphemic structure was lost. Their results were that the two word types produced equivalent transposed-character priming effects.

What Gu et al.'s (2015) result suggests is that there is little evidence for transposed morphological priming in Chinese in a lexical decision task, at least when using two-character words. More centrally to present purposes, however, what Gu et al.'s manipulation provides is a means of asking whether the masked priming same-different task is immune to morphological priming in Chinese, just as it is in Spanish and Hebrew. If the answer is yes, as will be described subsequently, the task will provide a basis for examining the question of the impact of morphological priming for four-character Chinese words in Experiment 3.4. Experiment 3.3 was, therefore, carried out to test whether the masked priming effect in the same-different task for Chinese readers has a morphological component by using Gu et al.'s stimuli and manipulations.

3.4.1 Method

Participants. Sixty-two undergraduate students from Hunan University of Science and Technology participated in this experiment. All received a small gift for their participation, were native speakers of Chinese, indicated that they were highly proficient in reading Simplified Chinese and had normal or corrected-to-normal vision with no reading disorder.

Materials. For the "same" trials, I used the same 120 two-character simplified words (60 single-morpheme words and 60 two-morpheme words) that Gu et al. (2015) used in their Experiment 3.1. The targets' mean word frequency (per million) is 1.58 (range: 0.12-5.88). The frequency of single-morpheme words (M = 1.59, SD = 1.28) is virtually identical to that for the two-morpheme words (M = 1.57, SD = 1.26), p > .10. Two different types of primes for each word target were used, (1) transposed character primes (e.g., reference: 拖沓(AB)- prime: 沓拖(BA)- target: 拖沓(AB)) and (2) unrelated primes (e.g., reference: 拖沓(AB)- prime: 肴肿(EF)- target: 拖沓(AB)), which contain no character also contained in the target. These word targets were divided into 2 counterbalanced lists with 30 stimuli in each condition, mimicking the prime-target assignment manipulation used in Experiment 3.1.

I also selected another 240 two-character simplified Chinese words for the “different” trials, 120 to be used as reference stimuli and 120 to be used as targets. The target mean word frequency (per million) is 1.52 (range: 0.03-14.64). On the different trials, I did not manipulate the morphemic status of the targets, because there is only a limited number of two-character single-morpheme words in Chinese. So each different target was primed by either a transposed prime (e.g., reference: 衰减- prime: 率表(DC)- target: 表率(CD)) or an unrelated prime (e.g., reference: 房产- prime: 身面- target: 海底) where the initial character string in the examples is the reference stimulus. (The related primes were related to the target stimuli rather than the reference stimuli.) For the different trials, only one list of primes and targets was created with 120 pairs in the two conditions. The reference stimuli and primes were presented in 35-point Boldface font whereas the targets were presented in 40-point Song font. The other details were the same as in Experiment 3.1. The reference stimuli, primes and their associated word targets for same trials are listed in the Appendix.

Procedure. The stimuli were presented on a 19.5-inch CRT monitor using a refresh rate of 60HZ (16.67ms). The screen resolution was 1360 x768. The sequence of stimuli on each trial was: the reference stimulus was initially presented for 1000 ms above a forward mask (######). The prime was then presented in the same position as the mask for 50 ms, and then it was replaced by the target for 3000 ms or until the participant responded. Participants were asked to decide whether the reference stimulus and the target were the same. They were instructed to press the “J” button if these two words are the same and the “F” button if they are different. The experimental block included 240 trials in total, 120 same trials and 120 different trials respectively. Participants received twelve practice trials prior to the experimental block. The other details were the same as in Experiment 3.1.

3.4.2 Results

Response latencies less than 300 ms (1% of the data), more than 3 standard deviations from the participant's mean latency (1.3% of the data) and from incorrect trials (8.5% of the data) were excluded from the latency analyses. The data from different targets were not analyzed due to the fact that the different targets were not counterbalanced across prime types. Morphemic Type (single-morpheme words vs. two-morpheme words) and Relatedness (transposed vs. unrelated) were treated as fixed effects (Baayen, 2008; Baayen et al., 2008). The final statistical model for the latency data was: RT = glmer (RT ~ Morphemic Type*Relatedness + (Relatedness |subject) + (Relatedness |item), family = Gamma (link="identity"), control = glmerControl(optimizer = "bobyqa", optCtrl = list (maxfun=1e6))). In the error analysis, the final model was: Accuracy = glmer (accuracy ~ Morphemic Type*Relatedness + (Relatedness |subject) + (Relatedness |item), family = "binomial", control = glmerControl(optimizer = "bobyqa", optCtrl = list (maxfun=1e6))). The other details were same as in Experiment 3.1. The mean RTs (in ms) and percentage error rates for Experiment 3.3 are shown in Table 7 for the same targets.

Table 7: Mean Lexical Decision Latencies (RTs, in Milliseconds) and Percentage Error Rates for Targets on the "same" trials in Experiment 3.3

	Single-morpheme condition		Two-morpheme condition	
	RT	%E	RT	%E
Related	517	5.1	525	6.5
Control	581	11.5	585	12.4
Priming	64	6.4	60	5.9

Note. RT= reaction time; %E=percentage error rate. The overall mean RT and error rate of the nonword targets were 552 ms and 4.3% respectively.

In the latency data, there was a significant main effect of Relatedness, *ß* = -30.315, *SE* = 3.288, *z* = -9.22, *p* < .001, with faster latencies for targets following transposed primes (521 ms) than targets following unrelated prime (583 ms). The main effect of Morphemic Type was not significant, *ß* = -2.398, *SE* = 2.32, *z* = -1.04, *p* = .301, nor was the interaction between Morphemic Type and Relatedness, *ß* = 0.111, *SE* = 1.996, *z* = 0.06, *p* = .956.

In the error rate analysis, the main effect of Morphemic Type was significant, *ß* = 0.093, *SE* = 0.045, *z* = 2.07, *p* = .039, with slightly more errors in the two-morpheme conditions (9.4%) than in the single-morpheme conditions (8.3%). There was also a main effect of Relatedness, *ß* = 0.489, *SE* = 0.073, *z* = 6.72, *p* < .001, with more errors in the unrelated conditions (11.9%) than in the transposed conditions (5.8%). More importantly, the interaction between these two factors was not significant, *ß* = 0.045, *SE* = 0.051, *z* = 0.87, *p* = .384.

A Bayes Factor analysis was conducted to evaluate the statistical evidence for the null interaction. The Bayes Factor BF_{01} was calculated using the BIC values for the model with no interaction (the null hypothesis H_0) and for the model with an interaction between Morphemic Type and Relatedness (the alternative hypothesis H_1). The other details are the same as those for the analyses in Experiment 3.1. In Experiment 3.2, The Bayes Factor, BF_{01} = 81.36, in Jeffreys's (1961) classification scheme indicates "strong" evidence for the null hypothesis (i.e., the absence of an interaction).

3.4.3 Discussion

The results of Experiment 3.3 imply that the masked priming same-difference task is not sensitive to morphologically-based priming, results that are very similar to Gu et al.'s (2015) results obtained in the masked priming lexical decision task. Gu et al.'s original result, by itself, suggests that the backward priming Yang et al (2019) observed did not have a morphological component. Equally importantly, for purposes of the procedure used in Experiment 3.4, these results support the conclusion derived from the literature (Duñabeitia et al., 2011; Kinoshita et al., 2012) that this task is not susceptible to morphological priming. As such, this task using the four-character stimuli from Experiment 3.1 can provide a basis for examining the question of whether the priming effects of the sort reported both by Yang et al. (2019) and observed in Experiment 3.1 have a morphological basis.

3.5 Experiment 3.4

In Experiment 3.4, the task used was again the masked priming same-different task, with the stimuli being essentially the same as those in Exeriment 3.1. As Experiment 3.3 and the previous literature suggest, priming in the same-different task has no morphological component. Therefore, by virtue of the fact that, as Experiments 3.1 and 3.2 have demonstrated, phonological priming does not emerge for four-character Chinese primes and targets, the priming observed in Experiment 3.4 should be entirely orthograpically-based. As a result, the effect that emerges in Experiment 3.4 should be the same size as the effect in Experiment 3.1 if the effect in Experiment 3.1 is also entirely orthographically-based.

3.5.1 Method

Participants. Thirty undergraduate students from Western University participated in this experiment. All received course credit for their participation, were native speakers of Chinese, indicated that they were highly proficient in reading Simplified Chinese and had normal or corrected-to-normal vision with no reading disorder.

Materials. The “same” trial word targets and their primes were those stimuli used in Experiment 3.1 with one additional target (and its primes) being added to replace the target that was presented twice in Experiment 3.1. The targets’ mean word frequency (per million) in the *SUBTLEX-CH* database (Cai & Brysbaert, 2010) is 1.63 (range: 0.03-48.5). Only backward priming was involved in Experiment 3.3. Two different types of primes for each word target were used, (1) backward primes (e.g., reference: 有所不同(ABCD)- prime: 同不所有(DCBA)-target: 有所不同(ABCD)); and (2) unrelated primes (e.g., reference: 有所不同(ABCD)- prime: 灭自生自(EFGH)- target:有所不同(ABCD)). The word targets were divided into 3 counterbalanced lists with 80 stimuli in each condition mimicking the prime-target assignment manipulation used in Experiment 3.2.

I also selected another 320 four-character simplified Chinese words for the “different” trials, 160 to be used as reference stimuli and 160 to be used as targets. Their mean word frequency (per million) is 0.24 (range: 0.21-0.27). I used a “zero-contingency scenario” on different trials (Perea, Moret-Tatay, & Carreiras, 2011), which means that the related primes were related to the reference stimuli rather than the targets.[2] Each target was primed by either a backward prime (e.g., reference: 掩耳盗铃(ABCD)- prime: 铃盗耳掩(DCBA)- target: 火眼金睛) or an unrelated prime (e.g., reference: 世风日下- prime: 生而运应- target: 无事生

非) where the initial character string in the examples is the reference stimulus. The backward prime had all the same characters as the reference stimulus, however, those characters were presented in a right-to-left direction. Unrelated primes were a different set of four-character simplified Chinese nonwords created by presenting the characters in an unrelated word in a right-to-left direction. Only one list of primes and targets was created with 80 pairs in each condition for the “different” trials. The reference stimuli and primes were presented in 35-point Boldface font whereas the targets were presented in 40-point Song font. The other details were the same as in Experiment 3.1.

Procedure. The experimental block included 320 trials in total, 160 “same” trials and 160 “different” trials respectively. Participants received eight practice trials prior to the experimental block. The other details were the same as in Experiment 3.3.

3.5.2 Results

Response latencies less than 300 ms (0.5% of the data), more than 3 standard deviations from the participant’s mean latency (2% of the data) and from incorrect trials (6.4% of the data) were excluded from the latency analyses. The data from different targets were not analyzed due to the fact that the different trials were not counterbalanced across prime types. Only one single fixed effect was involved in this experiment, Relatedness, with two levels (backward vs. unrelated). The final statistical model for the latency data was: RT = glmer (RT ~ Relatedness + (Relatedness |subject) + (Relatedness |item), family = Gamma (link="identity")). In the error analysis, the final model was: Accuracy = glmer (accuracy ~ Relatedness + (Relatedness |subject) + (Relatedness |item), family = "binomial", control = glmerControl(optimizer = "bobyqa", optCtrl = list (maxfun=1e6))). The other details were same as in Experiment 3.1. The mean RTs (in ms) and percentage error rates for Experiment 3.4 are shown in Table 8 for the same targets.

Table 8: Mean Lexical Decision Latencies (RTs, in Milliseconds) and Percentage Error Rates for same targets in Experiment 3.4

Condition	RT	%E
Backward prime	603	4.1
Unrelated prime	656	9.4
Priming	53	5.3

Note. RT= reaction time; %E=percentage error rate. The overall mean RT and error rate of the different targets were 665 ms and 3.3% respectively.

In the latency data for the "same" trials, the main effect of Relatedness was significant, *ß* = -26.854, *SE* = 5.052, *z* = -5.32, *p* < .001, with targets following the backward primes (603 ms) being significantly faster than targets following unrelated primes (656 ms). The Relatedness effect was also significant in the error rate analysis, *ß* = 0.514, *SE* = 0.102, *z* = 5.02, *p* < .001, with there being more errors in the unrelated condition (9.4%) than in the backward condition (4.1%).

I further contrasted the priming effect in Experiment 3.4 with the backward priming effect in Experiment 3.1. Task (masked lexical decision task vs. masked same-different task) and Relatedness (related vs. unrelated) were treated as fixed effects (Baayen, 2008; Baayen et al., 2008). The final GLMM analysis model used here for the latency data was: RT = glmer (RT ~ Relatedness*Task + (Relatedness|subject) + (Relatedness|item), family = Gamma (link="identity"), control = glmerControl(optimizer = "bobyqa", optCtrl = list (maxfun=1e6))). In the error analysis, the final model was: Accuracy = glmer (accuracy ~ Relatedness*Task + (Relatedness|subject) + (Relatedness|item), family = "binomial", control = glmerControl(optimizer = "bobyqa", optCtrl = list (maxfun=1e6))).

In the latency data, the main effect of Relatedness was significant, *ß* = -27.930, *SE* = 3.191, *z* = -8.75, *p* < .001, with targets following the backward primes (632 ms) being significantly faster than targets following unrelated primes (686 ms). The main effect of Task was also significant, *ß* = 26.651, *SE* = 3.839, *z* = 6.94, *p* < .001, with latencies in the same-different task (629 ms) being significantly faster than latencies in the lexical decision task (686 ms). Importantly, there was no hint of an interaction between Task and Relatedness, *ß* = -0.334, *SE* = 3.276, *z* = -0.10, *p* = .919. In the error rate analysis, these two main effects of Task and

Relatedness were also significant, *ß* = 0.215, *SE* = 0.110, $z = 1.96$, $p = .05$; *ß* = 0.402, *SE* = 0.081, $z = 4.97$, $p < .001$, with there being more errors in the unrelated condition and in the same-different task. Again, there was no interaction between Task and Relatedness, *ß* = -0.100, *SE* = 0.056, $z = -1.78$, $p = .075$.

A Bayes Factor analysis was conducted to evaluate the statistical evidence for the null interaction. The Bayes Factor BF_{01} was calculated using the BIC values for the model with no interaction (the null hypothesis H_0) and for the model with an interaction between Task and Relatedness (the alternative hypothesis H_1). The other details are the same as those for the analyses in Experiment 3.1. In Experiment 3.4, the Bayes Factor, $BF_{01} = 88.51$, in Jeffreys's (1961) classification scheme indicates "strong" evidence for the null hypothesis (i.e., the absence of an interaction).

3.5.3 Discussion

In Experiment 3.4, I found a significant backward priming effect (53 ms) in the masked priming same-different task. That effect size was essentially the same as that observed in the lexical decision task used in Experiment 1 (54 ms). Given that priming effects in the same-different task appear to be mainly orthographically-based, this equality, when considered in the context of the null phonological priming effects in Experiments 3.1 and 3.2, suggests that the backward priming effect obtained for Yang, Chen et al.'s (2019) Chinese readers processing four-character targets in the lexical decision task is essentially entirely orthographically-based.

3.6 Experiment 3.5

Even though both Experiments 3.3 and 3.4 provide evidence for the argument that there is no meaning-based priming component in Yang, Chen et al.'s (2019) backward priming effect, both of those experiments used a different paradigm (the masked priming same-different task) than used by Yang, Chen et al. and cross-paradigm comparisons can be problematic. Experiment 3.5, therefore, represents a further attempt to evaluate this issue. As noted, Japanese Kanji script (e.g., 安以宇衣於) is derived from Chinese script meaning that it is also a morphologically-based logographic script. Therefore, transpositions in Kanji are, like transpositions in Chinese, morphological, orthographic and phonological/syllabic. In contrast, the other two Japanese scripts, Katakana (e.g., アイウエオ) and Hiragana (e.g., あいうえお), convey no morphological information and, therefore, transposed characters in Katakana and Hiragana represent only phonological/syllabic and orthographic transpositions.

What this situation allowed us to do was to create transpositions involving Kanji, as well as Katakana, targets and to then compare the sizes of the priming effects in the two cases. To the extent that Kanji transpositions produce larger priming effects, that would be evidence for a morphological/meaning-based influence. If the priming effects are not larger with Kanji transpositions, the implication would be that, consistent with the conclusion drawn from the contrast of Experiments 3.1 and 3.4, meaning relationships play little, if any, role in producing tranposed character priming effects in logographic scripts.

Four types of primes were used in Experiment 3.5 for both Kanji and Katakana (four-character) targets. Target script was constant within a block of trials. In all cases, the primes and targets had the same characters in positions one and four. Therefore, the TC focus was on the middle two positions. One condition was a repetition condition, in which the prime and target had identical characters in positions two and three as well (e.g., in English, ABCD-ABCD).[3] The more central conditions involved the various types of substitutions/transpositions. The second condition was a TC condition in which the characters in positions two and three were transposed (e.g., ACBD-ABCD). The third condition was the standard control condition for the TC condition, a substituted character (SC) condition in which those two transposed characters were substituted (e.g., AYSD-ABCD). For the Kanji targets, the TC-SC contrast potentially involved contributions from all three factors, orthography, morphology and phonology. For the Katakana targets the TC-SC contrast potentially involved contributions from only orthography and phonology (see Table 9). Therefore, if TC priming for logographic words is at all meaning based, one would expect a larger TC priming effect for the Kanji targets.

Table 9: Potential sources of priming from the middle two characters in the TC, Hiragana TC and SC primes in Experiment 3.5

Prime types	Kanji targets	Katakana targets
Transposed Character (TC)	Orthographic, Phonological, Morphological	Orthographic, Phonological
Hiragana TC	Phonological	Phonological
Substituted Character (SC)	none	none

One potential problem with this contrast, however, is that it is based on the assumption that phonological priming is equivalent for Kanji and Katakana targets. As Experiments 3.1 and 3.2 demonstrate, phonological priming in logographic scripts is not particularly potent. However, given that Katakana is a shallower script, it is possible that there may be a noticeable phonological priming effect for Katakana targets (see Hsin-Chin Chen, Yamauchi, Tamaoka, & Vaid, 2007; Perea & Pérez, 2009; Yoshihara, Nakayama, Verdonschot, & Hino, 2017, for evidence that phonological priming effects are larger for Katakana targets than for Kanji targets). If so, it would be possible that Kanji and Katakana targets may produce an equivalent TC-SC difference even though those differences are based on different factors (i.e., orthographically- and meaning-based effects for Kanji targets, orthographically- and phonologically-based effects for Katakana targets), compromising the contrast we have created.

The way we addressed this issue in Experiment 3.5 was to contrast the SC condition with our fourth condition, a Hiragana TC condition, for the targets in the two scripts. In this condition, the middle two characters are written in Hiragana and transposed (again, see Table 9). The only type of priming that Hiragana TC primes should provide for either target type is phonologically-based. If the contrast between the SC and Hiragana TC conditions is larger for Katakana targets than for Kanji targets (i.e., if Hiragana TC primes are more effective primes for Katakana targets), that result would indicate that phonological priming was more effective for our Katakana targets than for our Kanji targets. Such a result would, therefore, as noted above, suggest that the contrast between the TC and SC primes for the two target types was compromised.

The present data would, however, provide a second contrast for evaluating morphological/meaning-based priming, one that should not be affected by any phonological priming differences between Kanji and Katakana targets (again, see Table 9). This contrast is the contrast between the Hiragana TC primes and the TC primes. As indicated in Table 9, both prime types could provide (transposed) phonological priming for both types of targets. As discussed above, the phonological priming available for the two target types may not be equivalent. What's important, however, is that the two prime types (TC and Hiragana TC) should provide equivalent degrees of phonological priming for a given target type. As a result, for Kanji targets, any TC vs Hiragana TC difference should be only orthographically- and/or morphologically/meaning-based, whereas, for Katakana targets, any TC vs Hiragana TC difference should be only orthographically-based. If TC priming is at all morphologically/meaning-based for the logographic Kanji targets, those targets should show a larger TC vs Hiragana TC difference than the Katakana targets.

3.6.1 Method

Participants. Ninety-six undergraduate students from Waseda University participated in this experiment. All received 1,000 yen for their participation, were native speakers of Japanese, indicated that they were highly proficient in reading Japanese Kanji, Katakana and Hiragana scripts and had normal or corrected-to-normal vision with no reading disorder.

Materials. Eighty four-character Kanji words (i.e., words that are typically written in Kanji) and eighty four-character Katakana words (i.e., words that typically written in Katakana) were chosen as the word targets. While many Kanji characters are pronounced with more than a single mora, only four-character Kanji words with the second and third characters that are only pronounced with only a single mora were used in this experiment. (Each Katakana character is pronounced with only a single mora.) The word frequency according to Amano and Kondo (2003) of the Kanji words (M = 443.35 per 287,792,787 words, SD = 1126.07) was virtually the same as that for the Katakana words (M = 445.16, SD = 1035.91), $p > 0.1$. Fifty-three participants who did not participate in the formal experiment rated the familiarity for each target word. The average target familiarity score for the Kanji words (M = 3.67, SD = 1.03) was also virtually identical to that for Katakana words (M = 3.69, SD = 0.96), $p > 0.1$. However, there are some differences between the two sets of words in term of summed numbers of strokes and summed character frequencies, $ps < 0.01$, even though an attempt was made to equate the word sets on these characteristics to the extent possible. The reasons are that Katakana characters consist of fewer numbers of strokes in general than Kanji characters and that character frequencies are generally higher for Katakana characters than for Kanji characters because there are fewer Katakana characters than Kanji characters.

There were four different types of primes for each Kanji and Katakana word target, (1) repetition primes, (2) transposed character (TC) primes, (3) substitution character (SC) primes, and (4) Hiragana TC primes. The repetition prime is the target itself (e.g., Kanji: 国語辞典− 国語辞典 (Japanese dictionary), Katakana:コンパス−コンパス (compass)). Transposed character primes are primes that transpose the middle two characters of word targets (e.g., Kanji:国辞語典 − 国語辞典, Katakana:コパンス− コンパス). Substitution character primes are primes that substitute the middle two characters of word targets with two new characters (e.g., Kanji:国総球典 − 国語辞典, Katakana:コイノス− コンパス). The two substitution characters did not share any orthography, morphemes or syllables with the targets (as shown in the above example). The Hiragana TC primes substituted the middle two characters of the TC prime with two Hiragana characters that have the same pronunciation as the two characters they were substituted for (e.g., Kanji:国じご典− 国語辞典, Katakana:コぱんス− コンパス), with those characters being presented in the reversed order from that in the target. The Kanji and Katakana targets were divided into 4 counterbalanced lists. Each list contained 20 stimuli that were to be in the same prime type condition. Each participant only saw each word (and nonword) target once and each list was presented to ¼ of the participants.

In addition, 80 four-character Kanji nonwords were created by combining 4 unrelated Kanji characters. Similarly, 80 four-character Katakana nonwords were also created by randomly combining four Katakana characters. The manipulation of prime type for the nonword targets was done in the same fashion as for word targets. However, only one list of primes and nonword targets was created for each script type. The primes and targets were presented using MS Gothic font with different sizes (12-point font for the primes and 16-point font for the targets).

Procedure. Data collection was accomplished by a program written using Microsoft Visual Studio 2015 with DX Libraries (C language libraries that use Direct X functions, https://dxlib.xsrv.jp/). The stimuli were presented on a 17-inch CRT monitor using a refresh rate of 60HZ (16.67ms). The screen resolution was 800 x 600. The general procedure was the same as in Experiment 3.1. The participants were asked to press the “Word” button on the button box connected to the PC via an I/O card (Contec, PIO-16/16T(PCI)H) if the presented target is a word and the “Nonword” button on the button box if it is a nonword as quickly and as accurately as possible. Script (Kanji vs. Katakana) was constant within a block and the order of the blocks was counterbalanced over participants, so that both Kanji and Katakana blocks were presented to each participant. Each experimental block included 160 trials in total, 80 word trials and 80 nonword trials. Before beginning each experimental block, participants received 16 practice trials (consisting of 8 word trials and 8 nonword trials).

3.6.2 Results

Ten word targets were excluded from the data analysis due to the fact that they produced error rates higher than 40%. Response latencies less than 300 ms (0.7% of the data), more than 3 standard deviations from the participant’s mean latency (1.7% of the data) and from incorrect trials (6% of the data) were excluded from the latency analyses. Two fixed effects were involved in this experiment, Prime Type, with four levels (repetition primes, TC primes, SC primes and Hiragana TC primes), and Script, with two levels (Kanji vs. Katakana). The function Anova in the Car package (Fox & Weisberg, 2016) was used to test for significance and to provide the *p* values, because the fixed factor Prime Type has more than two levels.

The final statistical model for the latency data was: RT = glmer (RT ~ Prime Type*Script + (1 |subject) + (1 |item), family = Gamma (link="identity"), control = glmerControl(optimizer = "bobyqa", optCtrl = list (maxfun=1e6))). In the error analysis, the final model was: Accuracy = glmer (accuracy ~ Prime Type*Script + (Script |subject) + (Script |item), family = "binomial""), control = glmerControl(optimizer = "bobyqa", optCtrl = list (maxfun=1e6))). The other details were same as in Experiment 3.1. The mean RTs (in ms) and percentage error rates for Experiment 3.5 are shown in Table 10 for the word targets.

Table 10: Mean Lexical Decision Latencies (RTs, in Milliseconds) and Percentage Error Rates for Words in Experiment 3.5

	Kanji		Katakana	
	RT	%E	RT	%E
Transposed Character (TC) prime	560	4.6	564	5.3
Hiragana TC prime	576	5.6	579	8.2
Substituted Character (SC) prime	585	6.5	606	11.3
Repetition prime	552	4.3	555	4.9

Note. RT= reaction time; %E=percentage error rate. The overall mean RT and error rate of the nonword targets were 588 ms and 1.9% respectively.

In the latency data, the main effect of Prime Type was significant, $\chi^2 = 378.373$, $p < .001$. The main effect of Script was not significant, $\chi^2 = 1.749$, $p = .186$. The interaction between these two factors was also significant, $\chi^2 = 32.644$, $p < .001$, suggesting that the data pattern was different for the Kanji and Katakana targets.

Ultimately, three contrasts in the interaction were regarded as being important to the main issue investigated here. In order to carry out those contrasts, in all three cases, we redid the glmer analysis as a 2 x 2 design. The first contrast was between the TC and SC conditions. A significant main effect of Prime Type ($\chi^2 = 153.87$, $p < 0.001$) and a nonsignificant main effect of Script were obtained ($\chi^2 = 2.30$, $p = 0.13$). There was also a significant interaction between Prime Type and Script, $\chi^2 = 12.43$, $p < .001$, due to the fact that the difference was 17 ms larger for Katakana targets than that for Kanji targets (a result that is in the direction opposite to the hypothesis of a meaning-based influence in TC priming for logographic targets). The contrasts were significant for both scripts (for Kanji word targets, $ß = 24.2$, $SE = 3.54$, $z = 6.83$, $p < .001$; for Katakana word targets, $ß = 43.0$, $SE = 3.96$, $z = 10.86$, $p < .001$.

Due to the fact that the contrast between the TC and SC conditions showed a significant effect in the unexpected direction (i.e., a larger effect for Katakana targets, which cannot benefit from meaning-based priming, than for Kanji targets) the second contrast that was undertaken was between the SC and Hiragana TC conditions. This contrast would index whether there is a difference in the size of the TC phonological priming effect (i.e., the Hiragana TC condition faster than the SC condition) in Katakana vs Kanji script. A significant main effect of Prime Type ($\chi^2 = 30.58$, $p < 0.001$) and a nonsignificant main effect of Script were obtained ($\chi^2 = 1.90$, $p = 0.169$). More importantly, a significant interaction was found, $\chi^2 = 19.54$, $p < .001$. Follow-ups indicated that the 27 ms difference for the Katakana targets was significant, $ß = 26.36$, $SE = 3.77$, $z = 6.98$, $p < .001$; whereas the 9 ms difference for the Kanji targets was not, $ß = 3.62$, $SE = 3.43$, $z = 1.05$, $p = .292$. This result supports the idea that the Katakana priming advantage in the initial contrast (i.e., TC vs SC) was a phonological effect, compromising the value of that contrast for evaluating the question of morphological priming.

The final contrast was between the TC and Hiragana TC conditions. In that contrast, only the main effect of Prime Type was significant, $\chi^2 = 55.11$, $p < .001$, with the TC condition being significantly faster than the Hiragana TC condition. The main effect of Script and the interaction did not approach significance (both ps > 0.1). Centrally, the lack of an interaction indicates that there was no additional priming for the Kanji targets in spite of the fact that they could have benefitted from the shared morphological relationships between the their TC primes and the targets whereas the Katakana targets could not. Indeed, the effect sizes were virtually identical (16 ms for Kanji targets, 15 ms for Katakana targets).

In the overall error rate analysis, the main effect of Prime Type was significant, $\chi^2 = 80.744$, $p < .001$, as was the main effect of Script, $\chi^2 = 7.075$, $p = .008$, (with more errors for Katakana targets (7.4%) than for Kanji targets (5.2%)), and the interaction between these two factors, $\chi^2 = 10.02$, $p = .018$. For Kanji targets, there were more errors in the SC condition than in the repetition condition and TC condition, with there being no significant difference among other conditions. For Katakana targets, there were more errors in the SC condition than in the repetition condition, TC condition or Hiragana TC condition. Hiragana TC primes also produced more errors than repetition primes and TC primes.

3.6.3 Discussion

The initial idea behind Experiment 3.5 was that it would provide two important contrasts for examining the impact of meaning-based contributions to TC priming effects in logographic character words, the TC condition against the SC condition and the Hiragana TC prime condition against the TC condition. Neither of these contrasts provided any evidence for such contributions. That is, neither contrast demonstrated that the Kanji targets, for which

TC meaning-based priming is possible, showed more priming than Katakana targets. In fact, the former contrast (TC vs SC) showed that the 42 ms priming effect for Katakana targets (e.g., コパンス - コンパス vs. コイノス - コンパス) was significantly larger than the 25 ms priming effect for Kanji targets (e.g., 国辞語典 - 国語辞典 vs. 国総球典 - 国語辞典).

The significant difference in the unexpected direction in the TC-SC contrast (i.e., a Katakana advantage), however, appears to have a simple explanation. It is due to the fact that phonological priming effects are larger for Katakana targets than for Kanji targets. (In fact, consistent with the results for Chinese targets in Experiments 3.1 and 3.2, as well as those reported by Chen et al. (2007) the phonological priming available for Kanji targets in lexical decision tasks appears to be quite small.) The basis for this claim is found in the contrast between the SC condition and the Hiragana TC condition for the two target types (e.g., コイノス - コンパス vs. コぱんス - コンパス; 国総球典 - 国語辞典 vs. 国じご典 - 国語辞典). That contrast is presumably based solely on (transposed) phonology (see Table 9). What that contrast showed is that Katakana targets clearly benefited from phonological priming (i.e., a significant 27 ms effect), whereas Kanji targets did not (i.e., a nonsignificant 9 ms effect). Based on that information, the expectation when considering the TC versus SC contrast would be that the Katakana targets would also benefit more from phonological priming than the Kanji targets. Therefore, any meaning-based priming advantage that the Kanji targets may have had in that contrast between TC and SC primes (if such an advantage exists) was, apparently, more than made up for by the phonologically-based priming advantage that the Katakana targets had.

The differential impacts of phonological priming for Katakana vs. Kanji targets implies, therefore, that the TC versus SC contrast does not provide a good means of evaluating the impact of morphological/meaning-based priming for Kanji targets. The other main contrast investigating morphological/meaning-based priming, that between the TC and Hiragana TC prime conditions (e.g., コパンス - コンパス vs. コぱんス - コンパス; 国辞語典 - 国語辞典 vs. 国じご典 - 国語辞典), does not suffer from a similar problem. That is, whatever phonological priming that may be available for Kanji targets would have been available from both the TC and Hiragana TC primes in the Kanji target condition and whatever (presumably larger) phonological priming that may be available for Katakana targets would have been available from both the TC and Hiragana TC primes in the Katakana target condition. Therefore, the only difference between effect sizes for the two prime types should be due to any added priming from meaning-based relationships for Kanji targets. The priming effects, however, were virtually identical for the two target types (16 ms for the Kanji targets, 15 ms for the Katakana targets).

Two other issues should be mentioned here. First, as noted, in our post hoc analysis of the interaction in Experiment 3.5, the results indicated that there was (transposed) phonological TC priming for Katakana targets (as the difference between the SC and Hiragana TC conditions was a significant 27 ms) but not for Kanji targets (the parallel difference was a nonsignificant 9 ms). The former result is consistent with Perea and Pérez’s (2009) results using Katakana targets, in which they obtained a significant masked transposed-mora priming effect (e.g., a.ri.me.ka - a.me.ri.ka) with the two results together indicating that transposed phonological priming, at least in certain circumstances is a real phenomenon. The lack of an effect for Kanji stimuli is, of course, consistent with the results from Experiments 3.1 and 3.2 using Chinese targets (and Chen et al., 2007), that phonology only plays, at most, only a minimal role in producing priming effects in logographic scripts in a lexical decision task.

The second issue concerns the nature of the priming available from Hiragana TC primes for Katakana targets. Every mora (i.e., phonological syllable) in Japanese can be represented by both a Hiragana character and a Katakana character. The argument has been made that the Katakana and Hiragana characters that share a pronunciation access the same abstract character/orthographic unit, paralleling the assumption made concerning uppercase and lowercase letters in Roman letter languages (Kinoshita, Schubert, & Verdonschot, 2019; Schubert, Gawthrop, & Kinoshita, 2018). If true, one could make the argument that the Hiragana TC primes would have been able to provide not only phonologically-based facilitation for the Katakana targets, but at least some orthographically-based facilitation in the same way that uppercase primes can produce orthographic priming of lowercase targets.

The claim that the processing of Hiragana and Katakana characters completely parallels the processing of uppercase and lowercase letters in alphabetic languages can’t be true in its strictest sense, however, since mixed script primes (i.e., character strings involving both Hiragana and Katakana characters, a KHKHK string) do not prime Katakana targets as well as Katakana primes do (Perea, Nakayama, & Lupker, 2017). In fact, Perea et al. reported that a prime of the sort (KHKHK) was only as effective as a prime created by entirely replacing the Hiragana characters with asterisks (e.g., K*K*K). In contrast, mixed uppercase and lowercase primes do appear to prime as effectively as same case primes do in alphabetic languages (Perea et al., 2015). More centrally for present purposes, however, is the question of, if Kinoshita et al.’s (2019) and Schubert et al.’s (2018) claim has some truth to it, how would that affect the viability of the present analysis?

As it turns out, even if their claim were true in that there was at least some orthographically-based priming available from the Hiragana TC primes for the Katakana targets, our conclusions concerning the TC vs Hiragana TC contrast for Kanji versus Katakana targets would still hold. That is, assume, for purposes of discussion, that the Hiragana TC primes do provide some orthographically-based priming for Katakana targets (but not for Kanji targets). Referring to the entries in Table 5, that means that the entry in the cell for Hiragana TC primes and Katakana targets would read, “phonological, some orthographic” (rather than just “phonological”), whereas the entry in the cell for TC primes and Katakana targets would still read, “phonological, orthographic”. If so, the contrast between these two conditions (empirically, a 15 ms difference) would not provide an uncontaminated estimate of the full impact of orthographic priming for Katakana targets in Experiment 5. Rather, the full impact would, presumably, be a bit larger. That is, only if the “baseline” condition (i.e., the Hiragana TC condition) had had no ability whatsoever to provide any orthographically-based facilitation, would the difference between it and the TC condition have reflected the full impact of orthographically-based facilitation (i.e., the 15 ms Hiragana TC vs TC difference may have slightly underestimated the impact of orthographically-based priming for the Katakana targets).

If this line of argument is correct, the implication is that there would be a bias for the Hiragana TC vs TC difference to be larger for the Kanji targets because those targets would show the full impact of orthographic priming in the Hiragana TC vs TC comparison. That is, this difference for Kanji targets could have been larger than that for Katakana targets purely due to extra orthographically-based facilitation for Kanji targets in the TC condition. (Any morphological/meaning-based facilitation that the Kanji targets received would also, of course, add to that difference.) Yet, the contrast between the TC and Hiragana TC conditions for Kanji targets produced only a 16 ms difference (versus the 15 ms difference for Katakana targets). Therefore, there is no evidence for either the idea that the orthographic priming effect was larger for Kanji targets or, more importantly, that those targets benefitted from any meaning-based priming. That is, even if we do assume that the Hiragana TC vs TC contrast was compromised for Katakana targets in that it involved some orthographically-based priming, the conclusion that there is no TC meaning-based priming for Kanji targets would not be challenged.

3.7 General Discussion

Five priming experiments involving the presentation of TC primes were carried out in order to understand the origins of the backward priming effect in lexical decision tasks in logographic scripts reported by Yang, Chen et al. (2019), specifically, whether it is based on processing at the orthographic, syllabic/phonological and/or morphological/meaning levels. Experiment 3.1 showed that there was no significant syllabic/phonological backward priming effect while at the same time replicating the overall backward priming effect reported by Yang, Chen et al. Experiment 3.2 was a demonstration that even forward syllabic/phonological primes produce little, if any, priming for four-character Chinese word targets in a lexical decision task. These results lead to the conclusion that syllabic/phonological information played essentially no role in producing Yang, Chen et al.'s effect. Experiment 3.3, involving a masked priming same-different task, indicated that task is not sensitive to morphological relationships, which set the stage for Experiment 3.4. Experiment 3.4, also involving a masked priming same-different task, demonstrated a significant backward priming effect (53 ms), which was equivalent in size to that obtained in the lexical decision task in Experiment 3.1 (54 ms), suggesting the Yang, Chen et al.'s backward priming effect, replicated in Experiment 3.1, was most likely entirely an orthographically-based effect. Experiment 3.5 was an investigation of TC priming in a logographic script using Japanese Kanji and Katakana words. Kanji characters, like Chinese characters are logographs whereas Katakana characters are syllables. As a result, morphological/meaning-based TC priming effects would only be possible for Kanji word targets. In neither of the relevant contrasts was the priming effect for Kanji word targets larger than that for Katakana word targets. Therefore, the overall conclusion that these data provide is that Yang, Chen et al.'s backward priming effect for four-character Chinese words in a lexical decision task is essentially an orthographically-based phenomenon, with any contributions of other factors being minimal at best.

At an empirical level, the finding that Yang, Chen et al.'s (2019) backward priming effect in the lexical decision task is not syllabic/phonological in nature may not be a great surprise (with the same being true for Japanese Kanji script, see Chen et al., 2007). For example, Shen and Forster (1999) found that the phonological priming effect for one character Chinese words was task specific. It was obtained only in a naming task but not in a lexical decision task. Additionally, in a lexical decision task, Zhou and Marslen-Wilson (2009) reported that pure pseudohomophone primes which replaced both characters of two-character compound words with homophonic characters did not produce a priming effect.

The reason for this inability to find phonological priming in lexical decision tasks in Chinese, however, does not seem to be due to the speed at which phonological information is activated by the prime. In other tasks, phonological priming has been observed with Chinese readers. Perfetti and Tan (1998), for example, have shown that phonological information is activated sufficiently rapidly to affect naming of Chinese single character words. In their masked priming naming experiments, there were four different types of primes: graphically related (e.g., 何 [what]//hé/ and 向 [towards]//xiàng/), homophonic (e.g., 其 [its]//qí/ and 齐 [together]//qí/), semantically related (e.g., 究 [research]//jiū/ and 查 [check]//chá/), and unrelated (e.g., 程 [journey]//chéng/ and 披[put on]//pī/). Perfetti and Tan also varied the prime-target stimulus onset asynchrony (SOA). Their main finding were that (1) at a short SOA (43 ms), only graphically related primes produced a facilitation effect for their single character target words; (2) when using a 57 ms SOA, homophonic primes produced a facilitation effect while semantically related primes showed a null effect, and graphically related primes produced an inhibition effect; (3) when using an 85 ms SOA, both homophonic primes and semantically related primes with a precise meaning facilitated the processing of the target words, and graphically related primes again produced an inhibition effect.

Other studies have also demonstrated that a masked phonological priming effect can be obtained in a Chinese one-character word naming task (Perfetti & Zhang, 1995; Zhou & Marslen-Wilson, 1999). A more recent event-related potential (ERP) study also found phonology does play at least a limited role in Chinese character recognition (Wong et al., 2014). Further, a masked phonological priming effect in logographic scripts has been found using a masked priming same-different task (Lupker et al. 2015; 2018; Yang et al., submitted), a task that does not require the retrieval of phonological information in order to respond accurately. These results do support the "early" phonological information activation idea proposed by the Universal Phonological Principle hypothesis (Perfetti, Zhang, & Berent, 1992). They also support, therefore, the idea that the reason one does not find priming in lexical decision tasks is that the processing structures used when making a lexical decision in Chinese are not affected by the activation of phonological information even when the order of that information is the same in the prime and target.

The conclusion that the backward priming effect has, at most, a minimal meaning-based component is, however, somewhat surprising. Although Chinese is normally talked about as being a logographic writing system, it also could be classified as a morphosyllabic writing system (Mattingly, 1992). That is, although each Chinese character is usually a single-syllable morpheme, most theorists do argue that the Chinese writing system is meaning-based instead of phonology-based (e.g., Perfetti & Liu, 2006). If so, morphological/meaning information is likely activated quite rapidly as well as being somewhat important in making lexical decisions about Chinese words.

Indeed, some Chinese word recognition models suggest that there is a separate morphological processing stage (in addition to a semantic processing stage) during Chinese word recognition (Zhang & Peng, 1992). Evidence supporting this idea comes from a number of studies. For example, Wu, Tsang, Wong and Chen (2017) investigated this issue using four types of primes for a given target (e.g., 公園[public park]) in a masked priming lexical decision task: 1) morphologically related primes, that is, primes sharing both a character and a morpheme with the target (e.g., 公眾[public citizen]), 2) homograph primes, that is, primes sharing only a character with the target (e.g., 公雞[rooster]), 3) semantically related primes that shared no characters with the target (e.g., 草地[lawn]) and 4) unrelated primes (e.g., 嗅覺[olfaction]). They found comparable P200s in the morphologically related and homograph conditions which both different compared to the unrelated condition, however, an N400 effect was only obtained in the morphologically related condition, with the semantic related condition producing a very weak effect. These results suggest an early and major impact of morphological information during Chinese word recognition.

In contrast, Taft and Zhu (1997b) have provided data arguing that morphemes themselves do not have a special role in processing Chinese as have Gu et al. (2015). As previously noted, using two-character words, Gu et al. reported that TC priming effects were similar for single-morpheme words (e.g., 哆嗦[tremble]) and two-morpheme words (e.g., 地震[earthquake]) in both latency data and eye tracking data. If TC priming effects were morphologically-based effects, one would have expected a larger priming effect for the two-morpheme words than for the single-morpheme words because a reversal of the characters in the single-morpheme words destroys the morphological relationship between the prime and target whereas a reversal of the characters in two-morpheme words does not.

Regardless of why meaning-based priming in Chinese emerges in some situations and not in others, what the present experiments do is to provide two pieces of evidence for the claim that the backward priming effect reported initially by Yang, Chen et al. (2019) and replicated in Experiment 1 is not meaning-based. One is the striking similarity of the effect sizes in Experiments 1 and 4 with the task in Experiment 4 being one that appears to be impervious to morphological influences. Certainly, an argument can be made that this contrast could be problematic as the nature of priming in the two tasks may be different. To sustain an argument of that sort, one would need to assume that the equality of effect sizes must have resulted from orthographic similarity having a smaller impact in one task (i.e., the lexical decision task in Experiment 3.1) than the other (i.e., the same-different task in Experiment 3.4) with the effect of morphology making up the difference. Such an argument would, of course, have to provide an explanation for why prime-target orthographic similarity is less impactful in one task than the other as well as how the two sources of priming (orthographic and meaning-based) might combine to enhance the priming effect in the task in which both are at play (i.e., lexical decision).

The second is the contrast between the priming patterns for Japanese Kanji versus Katakana words in Experiment 3.5. Kanji words are, like Chinese words, logographs that provide morphological/meaning-based information. As such it was possible to set up two contrasts that, if morphological/meaning-based information does contribute to TC priming, should have caused us to observe more priming for the Kanji words than for the Katakana words. In neither case did that result emerge and, in fact, one of the contrasts (TC vs SC priming) showed a signficant Katakana advantage, although that contrast was likely compromised by the fact that Katakana targets can be phonologically primed whereas four-character Kanji targets, like Chinese word targets, show little evidence of phonological priming in a lexical decision task.

The other important contrast in Experiment 3.5, that between the TC and Hiragana TC conditions, while based on a similar set of assumptions, does not appear to suffer a similar fate. TC and Hiragana TC conditions for the Kanji and Katakana targets would have both benefitted from whatever TC phonological priming was available for that particular target type. Therefore, the contrast between these two conditions would be an orthographic contrast for the Katakana targets and an orthographic plus meaning-based contrast for the Kanji targets. Assuming that the orthographic effects would be comparable for the two script types, the lack of a difference between the priming effects for the Kanji and Katakana targets then provides support for our claim that meaning-based information contributes little, if anything, to backward/TC priming with logographic words in a lexical decision task. Rather, these effects are most likely to be orthographic effects.

Our findings, therefore, raise a challenge for existing orthographic coding models, virtually all of which would not predict priming when the letter order in the target is completely reversed in the prime due to the fact that backward primes have little orthographic similarity with their forward targets. Certainly, the open-bigram models could not explain Yang, Chen et al.'s (2019) pattern as all but one of them, the Overlap open-bigram model (Grainger, Granier, et al., 2006), assumes that reverse open-bigrams are not activated. That is, for example, the backward nonword prime "elbat" does not activate the "ta" bigram or any other bigrams relevant to processing the target "table". Hence, "elbat" should not prime "table". Further, although the overlap open-bigram model does assume that reverse open-bigrams are activated, it also assumes activation levels that are, necessarily, quite minimal.

As Gu et al. (2015) suggest, however, it may be possible for the other type of model, the noisy-position models (e.g., Davis, 2010; Gómez et al., 2008), to address this challenge by assuming that Chinese readers develop a high tolerance for character position variance, a tolerance arising from the fact that there are very few anagrams in Chinese (and none for the types of stimuli used here and by Yang, Chen et al., 2019). Therefore, what is more important for Chinese readers is that the orthographic code accurately establish the character identities, rather than their positions, in the word being read. Essentially, the idea would be that a given string of characters typically has only one interpretation regardless of character order. For instance, when Chinese readers see a character string like "羊亡牢补", Chinese readers would quickly know this character string was likely meant to be the word "亡羊补牢". In contrast, when English readers see a letter string like "otps", they cannot know what word was intended as a considerable number of words can be generated from those four letters. Further, English readers need to deal with the fact that letters can appear in different positions or appear multiple times in a word (e.g., pneumonoultramicroscopicsilicovolcanoconiosis). As a result of these differences, the reading system for readers of Chinese would adapt to the fact that Chinese is not a position sensitive language while the system for readers of English (and of other alphabetic languages) would be required to take letter position somewhat more seriously. We should note, of course, that we are not the first to make an argument of this sort (e.g., Gu et al., 2015; Lally, Taylor, Lee, & Rastle, 2019; Lerner, Armstrong, & Frost, 2014; Taft, Zhu, et al., 1999).

The way that the noisy-position models would attempt to model orthographic coding in Chinese would be by increasing the values of the position uncertainty in those models. For example, in Davis's spatial-coding model, the σ parameter(s), or in Gómez et al.'s overlap model, the s parameters, could be scaled up. Doing so would have the required impact of increasing the similarity of the orthographic codes for forward and backward four-character strings. (Note that, in fact, the similarity scores for forward and backward letter strings when modeling reading in alphabetic languages are non-zero in these types of models now due to the fact that the middle characters are often reversals of one another, i.e., the "bl" in "table" and the "lb" in "elbat" create nonzero similarity scores.) Therefore, a change of this sort would be a quantitative one rather than a qualitative one.

Finding the correct setting for these parameters would not, however, be a simple process because the values of these position uncertainty parameters can't be increased without bound. The reason is that, as reported by Yang, Chen et al. (2019), there was a sizeable repetition priming effect for their four-character words (80 ms), an effect that was significantly larger than their backward priming effect (53 ms). This fact clearly implies that the system for Chinese readers must be coding for character positions to an extent that makes the code for a forward prime much more similar to that of the target than the code for a backward prime is. The challenge for the models would, therefore, be finding parameter settings that hit a sweet spot in terms of the system's sensitivity to position information.

3.8 Conclusion

The present research has shown that backward priming effects in reading four-character Chinese words are very unlikely to be phonologically-based nor meaning-based. Rather, the backward priming effect appears to be orthographically-based. A future step for model development would be to examine these issues in other languages in order to determine which languages produce a backward priming effect and, subsequently, whether any effect that does emerge is orthographically-based. For example, would backward priming effects be obtained in Arabic and Hebrew which are written right-to-left or would readers of those languages only produce priming when the prime is also written in their more familiar right-to-left format? Or, alternatively, possibly only readers who learn to read text in two orientations, both the left-to-right orientation and the top-to-bottom orientation (e.g., Japanese and Chinese readers), would show backward priming as a result of the flexibility required for doing so, even if those individuals have had no actual experience reading right-to-left presented words.

3.9 Footnotes

[1] An unpublished experiment done in our lab, paralleling the experiments done in Spanish and Hebrew, has also demonstrated no morphological priming in the masked priming same-different task using English words.

[2] Following Perea et al.'s (2011) demonstration that the nature of the different trials (i.e., whether the related prime is related to the reference stimulus or the target) produced different results on different trials (i.e., inhibition effects often emerge in the former situation, but no effects are ever found in the latter), Experiment 3.4 was run using their zero-contingency approach. At present, there is no evidence that the approach chosen for the different trials has any impact on results on same trials.

[3] The main purpose of the repetition prime conditions was that, in case there were no differences among the other conditions, the expected shorter latencies in the repetition conditions would indicate that the experimental design was sensitive enough to pick up true differences. Indeed, the repetition conditions were the fastest conditions for both script types.

Chapter 3.1 (Summary and Transition)

In Chapters 2 and 3, I obtained significant backward priming effects with four-character Chinese words in several experiments. The results in Chapter 2 (and in Experiment 3.1 of Chapter 3) contrast with the result that extreme TL priming effects do not show up with English readers (Guerrera & Forster, 2008). For example, using forward targets, although Guerrera and Forster (2008) did obtain a priming effect when a prime shared all its letters with the target while having only the two outside letters in the same position as in the target (e.g., sdiwelak-SIDEWALK), they failed to obtain any priming effect with more extreme transposition conditions. Contrasted with Chapter 2's and 3's data, these results imply that the level of flexibility in coding letter position during orthographic processing is different for Chinese readers (readers reading a logographic script) than for English readers (readers reading an alphabetic script, see also Yang, Jared, et al., 2019).

One possible interpretation of these results is that, in English, the orthographic coding process may be more affected by the orientation of the stimuli than in Chinese. Specifically, it is possible that the perceptual learning accounts of orthographic coding may be more viable for English readers. Hence the difference between Chinese and English is not one that is due to differences in the flexibility of the coding system but rather due the fact that the system has not learned how to deal, perceptually, with words appearing in unusual orientations.

One way to address this question is to evaluate how English readers deal with words in which the left-to right relationships among the letters is maintained but other spatial relationships are altered (i.e., the entire word itself is rotated). Manipulations of this sort should allow a more direct contrast between perceptual learning accounts and abstract letter unit accounts in a situation in which the participants do not produce high error rates.

Perea, Marcet, and Fernandez (2018) using Spanish readers have recently addressed this issue by comparing TL priming effects for marquee presented words and 90° rotated words, working under the assumption that the marquee words represented a somewhat familiar format of presentation because "Letters in marquee format have the same upright orientation as in canonical horizontal text" (p. 2). Their results showed similar TL priming effects for marquee and rotated words, allowing Perea et al. to argue for the abstract letter unit position.

Unfortunately, the contrast created by Perea et al. (2018) is problematic. Specifically, their participants appear to have had considerable difficulty with the marquee words as, overall, those words were actually responded to even more slowly (15 ms) than they responded to the rotated words. Therefore, it would seem that in order to create a truly appropriate comparison, the familiar condition would need to involve horizontally presented words, because, for both English and Spanish readers, that is the orientation that is most familiar to those readers.

Additionally, in order to examine the question of orientation in a theoretical meaningful way, one needs to know how unfamiliar the orientation should be in order to be able to legitimately assume that normal processing operations should be disrupted for letters in that orientation. As Whitney (2002) has argued, "the act of mental rotation decreases the amount of input reaching the letter nodes, and that this degradation increases with the amount of rotation" (p. 117) and, according to Dehaene et al. (2005), "letter detectors should be disrupted by rotation (>40°)" (p. 340). Indeed, previous research has repeatedly shown that reaction times are shorter for horizontal words/letters than for rotated words/letters that are rotated more than 40° (Chang et al., 2015; Koriat & Norman, 1985; Risko, Medimorec, Chisholm, & Kingstone, 2014). Hence, it does seem likely that letter rotation larger than 40° would be considered as unfamiliar format.

So in Chapter 4, I examined whether text rotation to different degrees (e.g., 0°, 90°, and 180° rotations) modulated TL priming effects in two experiments with English participants. In Experiment 4.1, I used a masked priming paradigm examining TL priming effects with horizontally presented text and 90° rotated text. Experiment 4.2, then, was designed to determine whether a similar result/conclusion would apply to an even more extreme orientation. Experiment 4.2 involved the same paradigm with the same stimuli as used in Experiment 4.1 with the text being rotated 180° (upside down presentations).

Chapter 4

4 Does Letter Rotation Decrease Transposed Letter Priming Effects?

4.1 Introduction

In most languages, words are typically written left-to-right horizontally. However, words in Chinese, Japanese and Korean are sometimes written vertically or, in Chinese, right-to-left horizontally. English readers, however, have limited experience in dealing with words written in different orientations, although some words can appear vertically, for example, the word “HOTEL” may appear vertically (in “marquee” format) in signs due to limited horizontal space. An important question for understanding the nature of orthographic coding is whether text orientation has an influence on the coding process. This question was addressed in the present research by examining the impact of text orientation on transposed letter (TL) priming effects (e.g., jugde priming JUDGE).

Most recent models of orthographic coding, such as the “noisy position” models (Adelman, 2011; Davis, 2010; Gómez, Ratcliff, & Perea, 2008; Norris & Kinoshita, 2012; Norris et al., 2010), and the “open-bigram” models (Grainger et al, 2006; Grainger & van Heuven, 2003; Schoonbaert & Grainger, 2004; Whitney & Marton, 2013; Whitney, 2001) can easily explain basic TL effects, however, none of these models concerns itself with the question of the influence of text orientation. Rather, in most of these models, the letter representations are simply assumed to be abstract.

One model that does explicitly deal with this issue was proposed by Dehaene, Cohen, Sigman and Vinckier (2005). In their local combination detectors (LCDs) model, the assumption is that at least some proportion of TL effects (in general) is due to the activity of bigram neurons. That is, the LCDs are not only sensitive to letters but also to local combinations of letters. In addition, those bigram neurons can tolerate certain position imprecision of the component letters. Importantly, the LCDs are derived via the perceptual learning process, so that they only encode frequent, informative letters and letter combinations.

In a similar vein, Grainger and Holcomb (2009) have suggested that letter detectors are based on the visuospatial location with respect to the reader’s eye fixation on the horizontal meridian. Letters in words that are presented in unfamiliar orientations require a transformation of the retinotopic coordinates into a special coordinate system in order to allow readers to successfully activate the open bigrams required for successful reading. The ability to do so develops through experience, which means that the usefulness of this special coordinate system would be affected by the characteristics of the input language. As a result of incorporating these types of spatially-based assumptions, models of this sort predict that TL effects should decrease (but not necessarily vanish) when a TL stimulus is presented in what is an unfamiliar spatial orientation for readers. I refer these ideas as the “perceptual learning account”.

The alternative assumption, and one which is adopted by most current models of orthographic coding, is typified by Witzel et al.’s (2011) abstract letter unit account. This account argues that “the mechanism responsible for TL priming operates at an entirely abstract level, in which the visuospatial relationships of the letters are irrelevant” (p. 915). According to this idea, the letter positions would be coded in an ordinal fashion (i.e., first-to-last, U is one or two letters before D in judge or jugde) instead of in terms of a visuospatial representations (e.g., horizontal versus vertical, U is on the left side of D versus above D), and this code allows the activation of lexical representations regardless of the presented word’s orientation. Based on this account, TL priming effects should be independent of the presented word’s orientation, that is, even those individuals who lack experience in reading text presented in non-canonical orientations should produce equivalent size TL priming effects regardless of the TL stimulus’s orientation.

There is now a considerable amount of evidence supporting the abstract letter unit account of orthographic coding. One primary source comes from results in masked repetition priming experiments in which the nature of the letters in the prime and target are different. One consistent finding is that these priming effects are the same size for targets precede by same case (e.g., TABLE-TABLE) versus different case (e.g., table-TABLE) primes (Grainger & Jacobs, 1993; Perea et al., 2014). Further, lowercase primes (e.g., table-TABLE) and mixed case primes (e.g., tAbLe-TABLE) were also equality effective in producing repetition priming effects (Perea et al., 2015). In contrast, the impact of text orientation on TL priming effects, and the question of whether perceptual learning processes may play a role in producing those priming effects, do not yet have an extensive literature.

In one of the initial attempts to test between perceptual learning and abstract letter unit accounts of masked TL priming effects when text orientation is varied, Witzel et al. (2011) examined TL priming effects for both Japanese-English bilinguals and monolingual English readers. Japanese-English bilinguals are used to reading both horizontally and vertically presented (in marquee format) Japanese words and horizontally presented English words, whereas they are unfamiliar with vertically presented English words. The expectation was that those readers would show equivalent size priming effects for horizontally and vertically presented Japanese words due to their familiarity with reading Japanese words in those two orientations. The more crucial empirical question was whether those readers would show similar size TL priming effects when reading familiar horizontally presented versus unfamiliar vertically presented English words, as their LCDs would not be well formed for the latter type of words due to those readers' lack of perceptual experience reading vertically presented English words.

In Experiment 1, Japanese-English bilinguals did show equivalent TL priming effects for horizontally and vertically (marquee) presented Japanese words (25 and 19 ms, respectively), and they also showed a TL priming effect for horizontally presented English words (35 ms). Marquee English words also produced a significant TL priming effect, however, it was noticeably smaller (15 ms) than the effect for horizontally presented English words. The contrast between vertically and horizontally presented English words was, however, compromised by a speed-accuracy tradeoff. Therefore, the results of Experiment 1 did not appear to clearly favor either account.

In their Experiment 2, Witzel et al. (2011) found a vertical (marquee) TL priming effect (22 ms) for native English readers. However, in this experiment, Witzel et al. did not include a horizontal condition, meaning that they could not compare the size of this TL priming effect with the size of the TL priming effect when these words were presented horizontally, making it difficult to conclude which account was best supported by their findings. Therefore, the question remained as to what the impact of text orientation on masked TL priming is for

English readers, that is, for readers who have little experience reading in any orientation other than left-to-right horizontal.

An attempt to follow up on Witzel et al.'s (2011) results was reported by Perea, Marcet, and Fernandez (2018) using Spanish readers (who also have generally read words that are written horizontally left-to-right). In this experiment, the authors compared TL priming effects for marquee presented words and 90° rotated words, working under the assumption that the marquee words represented a somewhat familiar format of presentation because “Letters in marquee format have the same upright orientation as in canonical horizontal text” (p. 2). Their results showed similar TL priming effects for marquee and rotated words, allowing Perea et al. to argue for the abstract letter unit position.

Unfortunately, the contrast created by Perea et al. (2018) is problematic. Specifically, their participants appear to have had considerable difficulty with the marquee words as, overall, those words were actually responded to slightly more slowly (15 ms) than the rotated words were. Therefore, it would seem that in order to create a truly appropriate comparison, the familiar condition would need to involve horizontally presented words, because, for both English and Spanish readers, that is the orientation that is most familiar to those readers.

Additionally, in order to examine the question of orientation in a theoretical meaningful way, one needs to know how unfamiliar the orientation should be in order to be able to legitimately assume that normal processing operations should be disrupted for letters in that orientation. As Whitney (2002) has argued, “the act of mental rotation decreases the amount of input reaching the letter nodes, and that this degradation increases with the amount of rotation” (p. 117) and, according to Dehaene et al. (2005), the LCD model suggests that “letter detectors should be disrupted by rotation (>40°)” (p. 340). Indeed, previous research has repeatedly shown that reaction times are shorter for horizontal words/letters than for rotated words/letters that are rotated more than 40° (Chang et al., 2015; Koriat & Norman, 1985; Risko et al., 2014). Hence, it does seem likely that Dehaene et al.'s estimate of > 40% is legitimate.

In the present experiments, therefore, the question was what is the impact of text rotation of both primes and targets to different degrees (e.g., 0° versus 90° and 180°) on TL priming effects? In Experiment 4.1, I used a masked priming paradigm examining TL priming effects with horizontally presented text and 90° rotated text. Based on Perea et al.’s (2018) results with 90° rotations, I expected those stimuli to produce a TL priming effect. If the effect is the same size as that in the horizontal condition, that result would provide evidence for an abstract letter unit account. Alternatively, if the letter input from rotated words really creates a processing cost (in the sense suggested by perceptual learning accounts), one would expect to find a smaller TL priming effect for 90° rotated words than for horizontally presented words.

To foreshadow, similar size effects were found for the two orientations, supporting the abstract letter unit account. Experiment 4.2, then, was designed to determine whether a similar result/conclusion would apply to an even more extreme orientation. Experiment 4.2 involved the same paradigm with the same stimuli as used in Experiment 4.1 with the text being rotated 180° (upside down presentations). According to perceptual learning accounts, the TL priming effects should greatly decrease or even vanish with 180° rotated words. In contrast, abstract letter/character unit accounts would not make such a prediction. Although there is likely a limit in terms of the degree of transformation the system would be able to successfully deal with (i.e., Davis, Kim & Forster (2008) failed to obtain any priming effects when the (English) primes and targets were both presented backwards), there is no *a priori* reason to assume that a 180° rotation would be outside that limit.

4.2 Experiment 4.1

4.2.1 Method

Participants. Thirty-eight undergraduate students from Western University participated in this experiment. All were native speakers of English and had normal or corrected-to-normal vision with no reading disorder.

Materials. Ninety-six single-syllable 5 letter word targets were selected from the English lexicon project (Balota et al., 2007). Their average SUBTLWF frequency is 42.05 (range: 2.08–453.98) and their mean orthographic neighborhood size (Coltheart, Davelaar, Jonasson, & Besner, 1977) is 4.07 (range: 0–13) (values obtained from the English Lexicon Project Database (Balota et al., 2007)). In addition, ninety-six single-syllable 5 letters nonwords were also selected. Each word target was preceded by two different types of primes, (1) a TL prime involving two middle adjacent transposed letters (e.g., *porve-PROVE*, the TL condition); (2) a substitution letter (SL) prime in which the two adjacent letters used in the TL condition were substituted with different letters (e.g., *pamve-PROVE*, the SL condition). The average position of first letter transposition/substitution was position 2.5. The same stimuli were used in the horizontal and rotated blocks, which means that each prime and target was presented twice.

The word and nonword targets were divided into two sets of size 48. Based on this division, two lists of stimuli were created. In one list, one set of targets was preceded by a TL prime with the other set of targets being preceded by an SL prime. In the other list, the prime-target conditions were reversed for all the targets. Each participant received the same list in the two (orientation) blocks, in order to minimize any difference between stimulus in two different orientations. Given the nature of the difference between the orientation blocks, it was expected that the repetition manipulation would not weaken the TL priming effects substantially in the second block (see Witzel et al., 2011). The manipulation of prime type for the nonword targets was done in the same fashion as for word targets, however, there was only one list of primes (48 TL primes and 48 SL primes) and targets. One half of the participants was assigned to each of these two lists. All primes were presented in 35-pt Courier New typeface, whereas the targets were presented in 40-pt Courier New typeface. (The prime and target are presented in different fonts and sizes in order to minize the visual overlap between them.) The stimuli used in this experiment are reported in the Appendix.

Procedure. The data were collected using Eprime 2.0 software (Psychology Software Tools, Pittsburgh, PA; see Schneider, Eschman, & Zuccolotto, 2002). The background color was white whereas the stimulus color was black. All the stimuli were presented centrally. The sequence of stimuli on each trial was seven hash marks (#######) presented for 500 ms, a lowercase prime for 50 ms and then an uppercase target presented for 3000 ms or until the participant’s response. Participants were asked to decide whether each presented string of uppercase letters was a real English word or not, pressing the “J” button if it is a real English word and the “F” button if not. They were asked to respond as quickly and as accurately as possible. Text orientation (horizontal vs. 90° rotation) was maintained within a block and the order of blocks was counterbalanced over participants. (Examples of text presented in different orientations are shown in Figure 3.) Trial order was also randomized for each participant. Each experimental block had 192 trials. Sixteen practice trials preceded each experiment block. This research was approved by the Western University REB (Protocol # 104255).

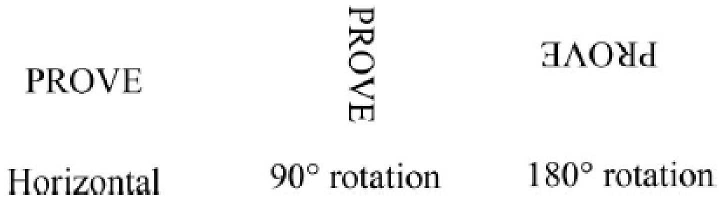


Figure 3: Examples of text presented in different rotation degree

4.2.2 Results

For word targets, response latencies less than 300 ms (0.2% of the data), more than 3 standard deviations from the participant’s mean latency (1.7% of the data) and from incorrect trials (5.7% of the data) were excluded from the latency analyses. The data from nonword targets were not analyzed due to the fact that the nonword targets were not counterbalanced across prime type. Before running the model, R-default treatment contrasts were altered to sum-to-zero contrasts (Levy, 2014; Singmann & Kellen, 2017).

Generalized Linear mixed-effects (GLMM) models from the lme4 packages were used to analyze the latency and error rate data (Bates et al., 2015; Lo & Andrews, 2015; “R Core Team,” 2015). I performed a generalized linear mixed-effects model analysis, instead of a linear mixed-effects model analysis, because the linear mixed-effects model analysis requires a normal distribution of RTs whereas raw RTs usually have a positively skewed distribution. Although this problem can be solved by analyzing inverted RTs (e.g., invRT = -1000/RT), doing so can change the size and pattern of interaction effects (Balota et al., 2013; Lo & Andrews, 2015). That is, the RT transformation can make the interaction smaller, vanish, or even reverse (Balota et al., 2013). Because interactions between factors were the focus of our experiments, we chose to use the GLMM analysis instead, as it allowed us to specify the RT distribution. I initially tried to use more complex models which included all relevant random structures in our analyses but I ultimately had to use a random intercepts only model due to convergence failures with the more complex models (Barr, 2013). For the latency analysis, the GLMM structure was: RT = glmer (RT ~ Prime Type* Orientation + (1|subject) + (1|item), family = Gamma(link="identity")). For the error rate analysis the GLMM structure was: Accuracy = glmer (accuracy ~ Prime Type* Orientation + (1|subject) + (1|item), family = "binomial"). The mean RTs and percentage error rates from a subject-based analysis for the word targets are shown in Table 11.[1]

Table 11: Mean Lexical Decision Latencies (RTs, in Milliseconds) and Percentage Error Rates based on the subject analysis

Condition	RT	%E
Horizontal		
Transposed prime	635	5.0
Substitution prime	668	7.0
Priming	33	2.0
Vertical 90° rotation		
Transposed prime	759	4.6
Substitution prime	788	7.0
Priming	29	2.4
180° rotation		
Transposed prime	986	10.7
Substitution prime	1021	13.5
Priming	35	2.8

Note. RT= reaction time; %E=percentage error rate. The overall mean RT and error rate of the nonword targets in horizontal orientation were 751 ms and 8.3% respectively; The overall mean RT and error rate of the nonword targets in 90° rotation orientation were 940 ms and 10.5% respectively. The overall mean RT and error rate of the nonword targets in 180° rotation orientation were 1275 ms and 12% respectively.

I also analyzed the nature of the priming effects across the latency distributions by examining quantile plots for each condition. The graphs of the latencies as a function of quantile can be seen in Figure 2. In order examine the quantile data statistically, I added Quantile Group as a fixed factor in a second analysis. For the latency analysis, the Quantile Group model was: RT = glmer (RT ~ Prime Type* Orientation* Quantile Group + (1|subject) + (1|item), family =

Gamma(link="identity")). The Quantile Group factor had four levels, with 10 trials in each of these levels. It should be noted that not all participants provided 10 trials in some conditions in the fourth quantile level and, in fact, I removed 1 participant's data from the Quantile Group analysis, because that person had less than 6 trials in the fourth quantile in one of the experimental conditions. Missing data was, of course, also a problem (to an even greater extent) for a fifth quantile level which could be created based on any remaining latencies. Therefore, I did not include the data from this fifth level in our analysis, however, the means for that level are shown in Figure 2. The function Anova in the Car package (Fox & Weisberg, 2016) was used to test for significance and to provide the p values for this analysis.

In the basic analysis of the latency data, the main effect of Prime Type was significant, $ß = 16.529$, $SE = 1.698$, $z = 9.74$, $p < .001$, as targets following SL primes (728 ms) were processed more slowly than targets following TL primes (697 ms). There was also a main effect of Orientation, $ß = -55.674$, $SE = 1.729$, $z = -32.21$, $p < .001$. Targets presented in the horizontal orientation (651 ms) were processed faster than targets presented in the vertical orientation (773 ms). More importantly, the interaction between those two factors did not approach significance, $ß = 0.680$, $SE = 1.656$, $z = 0.41$, $p = .681$, indicating that the priming effect was the same for the horizontal and vertical stimuli.

In the basic analysis of the error rate, the main effect of Prime Type was significant, $ß = -0.211$, $SE = 0.05$, $z = -4.19$, $p < .001$, indicating a tendency for targets in the SL conditions to elicit more errors (7.0%) than targets in the TL conditions (4.8%). The main effect of Orientation and the interaction between these two factors were not significant (both $ps > .10$).

In the Quantile Group analysis the default model failed to converge even when fitting was restarted from the apparent optimum. I then proceeded to re-run the model using all available optimizers. The results reported are the results from the BOBYQA optimizer. The three main effects of Prime Type, Orientation, and Quantile Group were significant (all $ps < .001$), as was the interaction between Orientation and Quantile Group, $\chi^2 = 438.48$, $p < .001$, which suggests that the latency difference between the horizontal and 90° rotation conditions increased from Quantile Group 1 to Quantile Group 4. The two-way interaction, Prime Type by Quantile Group failed to approach significance $\chi^2 = 1.86$, $p = .602$. Most importantly, neither the interaction between Prime Type and Orientation $\chi^2 = 0.07$, $p = .796$, nor the three-way interaction between Prime Type, Orientation and Quantile Group approached significance, $\chi^2 = 0.22$, $p = .974$. These results indicate that the overall priming effect was constant across quantiles and that such was the case in both Orientation conditions.

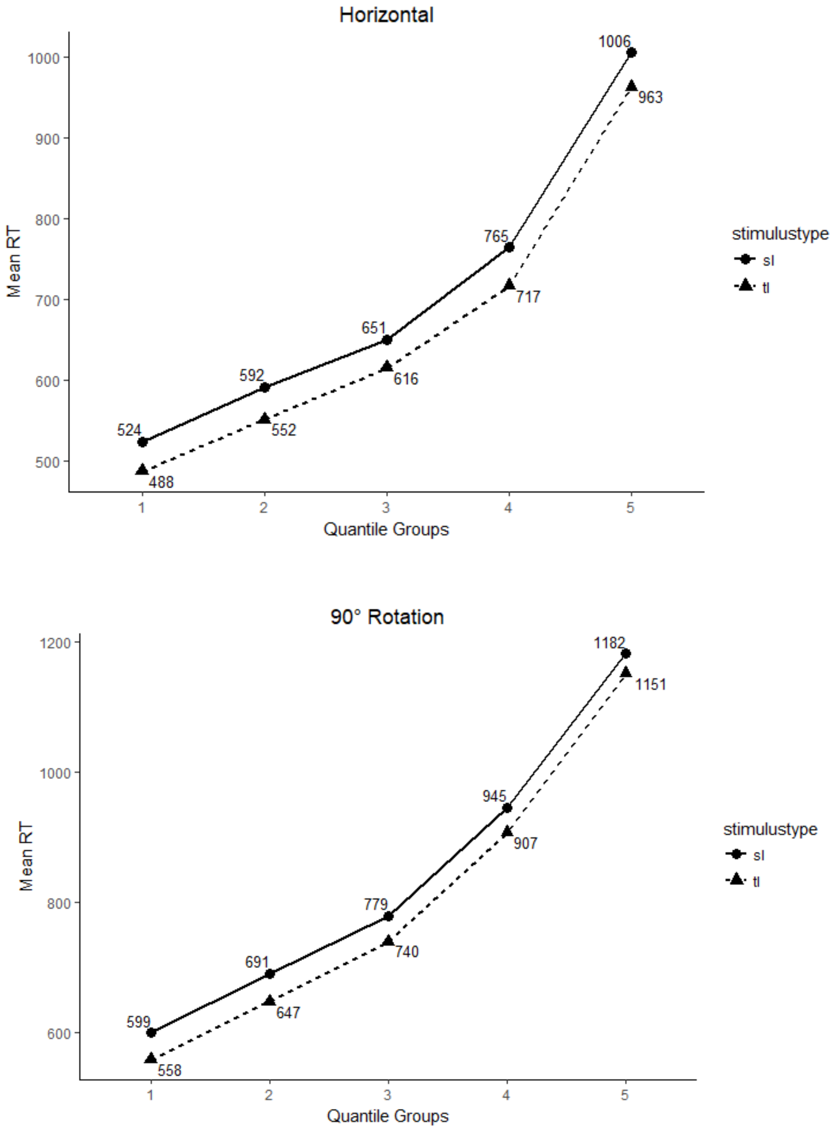


Figure 4: Quantile plot for Experiment 4.1

Note. The priming effects for Quantile Groups 1 to 5 were 36 ms, 40 ms, 35 ms, 48 ms and 43 ms respectively for the horizontally presented words. The priming effects for Quantile Groups 1 to 5 was 41 ms, 44 ms, 39 ms, 38 ms and 31 ms respectively for the 90° rotated words.

4.3 Experiment 4.2

4.3.1 Method

Participants. Forty Western University undergraduate students participated in Experiment 4.2. All were native speakers of English and had normal or corrected-to-normal vision with no reading disorder.

Materials. The materials were the same as in Experiment 4.1.

Procedure. The procedure was the same as in Experiment 4.1, except that the primes and targets were presented only in an (upside-down) 180° rotation orientation.

4.3.2 Results

For word targets, response latencies less than 300 ms (0.7% of the data), more than 3 standard deviations from the participant's mean latency (1.4% of the data) and from incorrect trials (11.3% of the data) were excluded from the latency analyses. The mean RTs and percentage error rates from a subject-based analysis for the word targets are shown in Table 11. The mean RTs from the subject-based analysis for the different Quantile Groups in Experiment 4.2 are shown in Figure 3.

For the basic latency analysis, the model was: RT = glmer (RT ~ Prime Type + (1|subject) + (1|item), family = Gamma(link="identity")). For the basic error rate analysis, the model was: Accuracy = glmer(accuracy ~ Prime Type + (1|subject) + (1|item), family = "binomial"). The other details were same as in Experiment 4.1.

In the latency data, the difference between TL (986 ms) and SL (1021 ms) conditions was significant, $ß = 20.421$, $SE = 3.655$, $z = 5.59$, $p < .001$. Targets following TL primes also produced significantly less errors (10.7%) than targets following SL primes (13.5%), $ß = -0.148$, $SE = 0.052$, $z = -2.86$, $p = .004$.

I further contrasted the priming effect in this experiment with those in the horizontal and vertical conditions in Experiment 4.1. The basic GLMM analysis paralleled that in Experiment 4.1 except that the Orientation factor now had three levels. I also carried out analyses that involved both having three levels of the Orientation factor and adding Quantile Group as a factor. As in the previous quantile analysis, I removed participants from this analysis if they had fewer than 6 trials in either Prime Type condition in quantile 4 (the 1 participant in Experiment 4.1 and 4 of the participants in Experiment 4.2).

In the basic analyses of both the latency data and error rate data, the two main effects of Prime Type and Orientation were significant (both *ps*<.001). Crucially, the interaction between those two factors did not approach significance in either the latency data, $\chi^2 = 0.85$, $p = .654$; or the error rate data, $\chi^2 = 1.02$, $p = .599$. [2]

In the Quantile Group analysis, the default model again failed to converge even when fitting was restarted from the apparent optimum. I then proceeded to re-run the model using all available optimizers. The results reported are the results from the BOBYQA optimizer. The three main effects of Prime Type, Orientation, and Quantile Group were significant (all *ps* < .001), and the interaction between Orientation and Quantile Group was also significant, $\chi^2 = 2288.28$, $p < .001$, which suggests that the latency difference between different orientations are increasing from Quantile Group 1 to Quantile Group 4. There was no significant interaction between Prime Type and Orientation, $\chi^2 = 1.64$, $p = .440$, however, there were marginal trends for the two-way interaction between Prime Type and Quantile Group, $\chi^2 = 7.02$, $p = .071$, and the three-way interaction between Prime Type, Orientation and Quantile Group, $\chi^2 = 11.97$, $p = .063$. These marginal interactions appear to be due to the growth in the priming effect in the fourth quantile in the 180° rotation orientation condition, a difference that narrowed considerably in the fifth quantile.

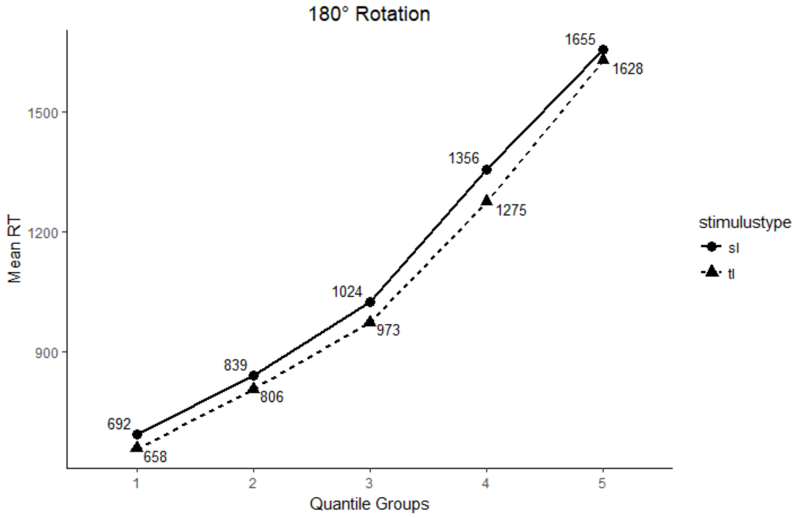


Figure 5: Quantile plot for Experiment 4.2

Note. The priming effects for Quantile Groups 1 to 5 were 34 ms, 33 ms, 51 ms, 81 ms and 27 ms respectively for the 180° rotated words.

4.4 General Discussion

Two experiments were conducted in order to examine the impact of rotated letters/words on TL priming effects and, in doing so, contrast a perceptual learning account (e.g., Dehaene et al., 2005) with an abstract letter unit account such as that presented by Witzel et al. (2011). To do so, I included three orientation formats in Experiments 4.1 and 4.2. In Experiment 4.1, I obtained similar size TL priming effects in the horizontal and 90° rotation orientations (33 ms and 29 ms, respectively). In Experiment 4.2 I found a significant TL priming effect with a 180° rotation orientation (35 ms). Importantly, the magnitude of TL priming effect in Experiment 4.2 was essentially the same as those in Experiment 4.1, supporting the conclusion that the TL priming effects do not vary as a function of the text orientations used here.

I further examined the nature of the priming effects as a function of quantile in the three orientation conditions. In the two conditions in Experiment 4.1, those effects were virtually identical across quantiles. In the 180° rotation condition in Experiment 4.2 there was some suggestion that the effect size did increase in the fourth quantile, however, the relevant interaction was not significant and there is also no evidence that the effect increased in size in the, admittedly fragile, fifth quantile. Identical size priming effects across quantiles are typically taken to imply that the prime provides a “headstart” to target processing (Balota, Yap, Cortese, & Watson, 2008) as a result of activating the target’s processing structures. Hence, the implication would be that the primes used in these experiments not only provided equivalent priming effects but they did so in essentially the same way (i.e., by boosting the activation of the target) regardless of their orientation (and that of the target). Such a conclusion would, of course, be consistent with the proposal that, in all instances, that activation is coming from the prior activation of a shared set of abstract letter units. That is, the facts that: 1) the rotated stimuli did not disrupt the size of the TL priming effect and 2) the quantile analyses showed that that effect is likely a headstart effect support the claim that a similar priming operation is at work in all three situations, an operation based on an abstract ordinal code, regardless of text orientation (e.g., Witzel et al., 2011).

In contrast, as Perea et al. (2018) have argued, a perceptual learning account would appear to have some difficulty explaining the equivalent overall effect sizes in the three presentation conditions. For example, in Dehaene et al.’s (2005) model, Engish readers would not have developed the local combination detectors that would allow them to process rotated words in the same way that they process canonical words. Therefore, the expectation is that the primes would be less effective when they are rotated, a result that did not obtain.

Do note, however, that our argument is not that the initial processing stages underlying the formation and use of the abstract orthographic code for familiar orientations versus unfamiliar orientations are identical.[3] As many behavioral studies have shown, unfamiliar formats (e.g., low text contrast words, MiXeD case words and vertically presented words) induce a strong length effect (Bub & Lewine, 1988; Lavidor, 2002; Legge, Ahn, Klitz, & Luebker, 1997), and functional Magnetic Resonance Imaging (fMRI) studies have shown that unfamiliar formats tend to produce a larger activation in the posterior visual word form area (Cohen, Dehaene, Vinckier, Jobert, & Montavont, 2008). Such results caused Cohen et al. to propose their perceptual expertise hypothesis which suggests a parallel word recognition process for letters in words presented in a familiar format and a (qualitatively different) serial reading strategy for words presented in an unfamiliar format (i.e., a format which is outside the readers’ field of expertise). As a result, position encoding for words in unfamiliar orientations requires attention shifts across the letters, leading to longer latencies.

In contrast, Whitney (2018) has presented experimental evidence for serial letter processing in both types of situations. The difference is that the rate of letter activation is faster for canonical presentations (~15 ms/letter) than for non-canonical presentations (~40 ms/letter or more) because the former allow the use of a more practiced mechanism (i.e., the distinction Whitney proposed is a quantitative rather than a qualitative one). Consistent with both proposals, of course, our 180° rotated words were identified as words more slowly (1003 ms) than 90° rotated words (773 ms), and they were both identified as words more slowly than horizontal words (651 ms). More importantly, the fact that the present data provide good support for the role of abstract letter units in all situations investigated here would appear to be more consistent with a quantitatively-based account such as Whitney's rather than a qualitatively-based account such as that proposed by Cohen et al. (2008).

Note also that the argument is not that perceptual learning processes would never play a role in orthographic coding but rather that the basis of orthographic coding in skilled readers is abstract letter units. As Grainger (2018) has described, orthographic processing is the interface between lower level visual processing and high level language processing. Visual processing mainly involves obtaining information about the featural components of a word's letters, and orthographic processing is mainly focused on deriving information about letter identities and letter positions. One can, therefore, make a strong ecological argument that it is computationally more effective to solve any visual shape invariance issues at the letter level (N= 26 for alphabetical language like English) instead of at some other level (e.g., for the word level, N= 30,000+). As such, it would make sense that our orthographic coding system would be tuned to recognize letters (and, therefore, words) independently of the precise form that the visual input takes (e.g., MiXeD case vs. pure case, lowercase vs. UPPERCASE, as well as printed words vs. handwritten words – Gil-López et al., 2011). That is, it would make sense that people would recognize letters and words via the use of abstract representations with the difficulties created by changes in orientation dealt with at the visual processing level instead of at the orthographic coding level.

A potential question this analysis raises, however, is to what extent these ideas apply to people trying to learn to read in an L2, particularly an L2 having a different script than that of their L1? As noted, Witzel et al. (2011) compared the TL priming effects in an unfamiliar vertical orientation to those in a standard horizontal orientation in English with Japanese-English bilinguals. Those individuals produced a smaller TL priming effect with marquee English words than with horizontal English words, in contrast to our results with English L1 readers, although, as noted, this contrast was compromised by a speed-accuracy tradeoff. If this difference is real, it may reflect a distinct difference between first language (L1) and second language (L2) readers. That is, the possibility exists that perceptual learning processes may play a role in the orthographic coding process when readers are learning to read in their L2 whereas the orthographic coding process in a reader’s L1 are, instead, based on abstract representations (i.e., representations that are independent of, among other things, the presented text’s orientation) and, importantly, those abstract representations are ones that may emerge only as a result of prolonged exposure to the script of that language.

4.5 Conclusion

Our results suggest that native English readers rapidly convert the unfamiliar visuospatial code of rotated words into an abstract letter-based code, the code that would then be used to drive subsequent (e.g. lexical, semantic) processing.

4.6 Footnotes

[1] The priming effects in terms of mean latencies from an item-based analysis for the horizontal, vertical 90° rotation and 180° rotation conditions were 34 ms, 31 ms and 31 ms, respectively. The priming effects in terms of percentage error rates from an item-based analysis were the same size as those reported for the subject-based analysis in Table 11.

[2] Note that, due to the fact that there were a number of long latencies, particularly in Experiment 4.2, I also explored (in both experiments) the impact of using a stricter outlier removing procedure, the recursive moving criterion procedure suggested by Van Selst and Jolicoeur (1994). In this procedure, a 3 standard deviation cutoff for removing RTs is used for the correct trials within each experimental condition for each participant and this procedure is conducted repeatedly (with a new mean and standard deviation calculated after each iteration) until there are no latencies outside 3 standard deviations in any experimental condition. This trimming process removed 9.4% of the experiment trials in Experiment 4.1 and 11% of the experimental trials in total for the comparison of the three orientations. After using this trimming procedure, I again compared the priming effects using the same GLMM analyses. The data pattern did not change. Crucially, when comparing the horizontal and 90° rotation orientations in Experiment 4.1, the interaction between Prime Type and Orientation was not significant, $\chi^2 = 1.75$, $p = .19$. When comparing the three orientations following Experiment 4.2, the interaction between Prime Type and Orientation was also not significant, $\chi^2 = 2.03$, $p = .36$.

[3] The authors would like to thank Carol Whitney for bringing these issues to our attention.

Chapter 5

5.1 Overall General Discussion

As described in Chapter 2, four masked priming experiments involving the presentation of stimuli in different orientations were carried out in order to investigate the range of situations in which Chinese words would show orthographic priming effects. The results in Chapter 2 were that repetition and TC priming effects were observed for stimuli presented in all investigated orientations, including orientations that do not produce priming in alphabetic languages. In particular, in Experiment 2.2 in Chapter 2, Chinese native readers showed masked repetition and TC priming effects when the text was presented in a right-to-left orientation. In Experiment 2.3, there again was a strong repetition effect and, what can be considered, TC priming effects when left-to-right targets followed right-to-left primes. Finally, even though Experiment 2.4 involved an entirely new text orientation, participants produced a TC priming effect that was virtually the same size as those in Experiments 2.1 and 2.2. These results provide clear evidence that orthographic priming effects, in particular, TC priming effects are more substantial in Chinese than in English with the results of Experiment 2.4 providing probably the clearest evidence for an abstract character unit account.

As described in Chapter 3, five priming experiments involving the presentation of TC primes were carried out in order to understand the origins of the backward priming effect in logographic scripts, specifically, whether it is based on processing at either the orthographic, syllabic/phonological and/or morphological/meaning levels. Experiment 3.1 showed that there was no significant syllabic/phonological backward priming effect while at the same time replicating the overall backward priming effect reported by Yang, Chen et al. (2019). Experiment 3.2 was a demonstration that even forward syllabic/phonological primes do not produce priming for four-character Chinese word targets. These results suggest that syllabic/phonological information is ineffective at producing priming in virtually any situation for four-character Chinese word targets. Experiment 3.4, involving a masked priming same-different task, a task that has shown no evidence that is based on morphology, demonstrated a significant backward priming effect (53 ms), which was equivalent in size to that obtained in Experiment 3.1 (54 ms). Experiment 3.5 was an investigation of TC priming in Japanese Kanji and Katakana words. Kanji characters, like Chinese characters are logographs whereas Katakana characters are syllables. As a result, TC priming effects based on morphology would only be possible for Kanji word targets. In neither of the relevant contrasts was the priming effect for Kanji words larger than that for Katakana words. Therefore, the overall conclusion that these data provide is that the backward priming effect is essentially an orthographically-based phenomenon, with any contributions of morphology being minimal at best.

As described in Chapter 4, two experiments were conducted in order to examine the impact of rotated letters/words on TL priming effects in English and, in doing so, contrast a perceptual learning account (e.g., Dehaene et al., 2005) with an abstract letter unit account such as that presented by Witzel et al. (2011) for English language readers. To do so, three orientation formats were used in Experiments 4.1 and 4.2. In Experiment 4.1, there were similar size TL priming effects in the horizontal and 90° rotation orientations (33 ms and 29 ms, respectively). In Experiment 4.2 there was a significant TL priming effect with a 180° rotation orientation (35 ms). Importantly, the magnitude of TL priming effect in Experiment 4.2 was essentially the same as that in Experiment 4.1, supporting the conclusion that the TL priming effects do not vary as a function of the text orientations used here. All in all, these results support abstract letter/character unit accounts of form priming effects in both languages while failing to support perceptual learning accounts, and, at the same time indicating that Chinese readers have more flexible (i.e., less precise) letter position coding than English readers. That is, Chinese readers produce backward priming effects whereas English readers can not produce priming effects from such extreme transpositions, with these backward priming effects being essentially orthographically-based. As a result, my results would appear to pose new challenges to existing orthographic coding theories. Table 12 summaries the results of every study of the present project.

Table 12: Masked priming effect size for different conditions across every study

Experiment	Language	Orientation	Repetition priming	Transposed letter/character priming	Phonological priming	Semantic/morphemic priming
Experiment 2.1	Chinese	Left-to-right	80	53		
	Chinese	Top-to-bottom	71	38		
Experiment 2.2	Chinese	Right-to-left	83	41		
Experiment 2.3	Chinese	Prime: Right-to-left Target: Left-to-right	52	56 (classic transpositions) 51 (external transpositions)		
Experiment 2.4	Chinese	Bottom-to-top		50		
Experiment 3.1	Chinese	Right-to-left	54		5	
Experiment 3.2	Chinese	Left-to-right			2	
Experiment 3.3	Chinese	Left-to-right				64 (Single-morpheme condition) 60 (Two-morpheme condition)
Experiment 3.4	Chinese	Left-to-right	53			
Experiment 3.5	Kanji	Left-to-right	33	25	9	
	Katakana	Left-to-right	51	42	27	
Experiment 4.1	English	Horizontal		33		
	English	90 degree rotation		29		
Experiment 4.2	English	180 degree rotation		35		

An obvious question to ask is why Chinese readers show priming effects whereas English readers don’t when the transformations are extreme (i.e., backwards). As mentioned previously, a reasonable hypothesis is that readers of nonalphabetic languages may be (empirically) differentially tolerant of position uncertainty than readers of alphabetic languages due to the nature of the scripts. In Chinese, for example, 97% of two-character words do not make another word when the order of characters is reversed. Further, four-character Chinese words, the words used here, are rare. As a result, most of the four-character Chinese words do not have many orthographic neighbors. Hence, a given string of characters may have only one interpretation regardless of character order. For instance, when Chinese readers see a character string like “养亡牢补”, Chinese readers would quickly know this character string was likely meant to be the word “亡羊补牢”. Whereas when English readers see a letter string like “otps”, they cannot know what word was intended as a considerable number of words can be generated from those four letters. Further, English readers need to deal with the fact that letters can appear in different positions or appear multiple times in a word (e.g., pneumonoultramicroscopicsilicovolcanoconiosis). As a result of these characteristics, the reading system for readers of Chinese would adapt to the fact that Chinese is not a position sensitive language (i.e., letter position is much less important than letter identity) while the system for readers of English would be required to take letter position somewhat more seriously.

Therefore, I would like to propose what can be called the Chinese character position free processing hypothesis. According to this hypothesis, the input information will activateboth the character identity and character position information, however, the character identity information has a much higher weight than character position information. This information will be used to activate the word level representations. Further, not only will the lower level representations activate the higher level representations, but also the higher level representations can give feedback to lower level representations. Even though the input information is quite position noisy, the character position can be reorganized by the feedback from the word level (feedback that may be driven to some extent by semantic information). As a result, character positions can be easily reorganized in a short time, although such recognition is not necessary for successful lexical access. Such would not be the case for English readers because many words have a lot of orthographic neighbors. Hence, English readers would have considerable difficulty reading ecaf as FACE even when the stimulus is clearly presented and they are told that the stimuli will be words presented backwards (Davis et al., 2008).

Guerrera and Forster (2008) have provided the most extensive examination of extreme transpositions in English. Those authors demonstrated a priming effect when a prime was created by maintaining the initial and final letters in eight-letter targets while the internal six letters were pairwise transposed (e.g., sdiwelak-SIDEWALK). However, Guerrera and Forster also showed that there are limits as they failed to obtain priming effects in more extreme transposition conditions, for example, when the prime was formed by pairwise transposing all eight letters in the target (isedawkl-SIDEWALK) or by reversing the order of both the first four and final four letters in the target (edisklaw-SIDEWALK). All in all, there is a limit to the amount of distortion in the ordering of letters that the system of English readers can tolerate, a limit that is different than the limit for Chinese readers. Successful models of orthographic coding in English will have considerable difficulty explaining the orthographic coding process in Chinese (and vice versa).

Our findings, therefore, appear to pose a challenge for existing orthographic coding models, virtually all of which, as currently conceptualized, would not predict priming when the letter order in the target is completely reversed in the prime due to the fact that backward primes have little orthographic similarity with their forward targets. Certainly, the open-bigram models could not explain Yang, Chen et al.'s (2019) pattern as all but one of them, the Overlap open-bigram model (Grainger, Granier, et al., 2006), assumes that reverse open-bigrams are not activated. That is, for example, the backward nonword prime "elbat" does not activate the "ta" bigram or any other bigrams relevant to processing the target "table". Hence, "elbat" should not prime "table". Further, although the Overlap open-bigram model does assume that reverse open-bigrams can be activated, it also assumes that their activation levels are, necessarily, quite minimal.

The way that the other type of orthographic coding model, the noisy-position models, would attempt to model orthographic coding in Chinese would be by increasing the values of the position uncertainty in those models. For example, in Davis's spatial-coding model, the σ parameter(s), or in Gómez et al.'s overlap model, the s parameters, could be scaled up. Finding the correct setting for these parameters would not, however, be a simple process because the values of these position uncertainty parameters can't be increased without bound. The challenge for the models would, therefore, be finding parameter settings that hit a sweet spot in terms of the system's sensitivity to position information. What should also be noted is that the spatial coding model would have additional trouble here because it assumes that there is a small inhibition effect from backward primes. Finally, because the network model proposed by Lerner, Armstrong and Frost (2014) was based on orthographic systems having very small numbers of symbols (as in English and Hebrew), it's unclear how a model of that sort could be scaled up in a way that would allow it to be applied to a logographic language like Chinese, as in Chinese, there are more than 5,000 orthographic symbols (i.e., characters).

One (noisy position) model that seemed to have some potential to explain the backward priming effect in Chinese was Gómez et al.'s (2008) overlap model. Using that model, I tried to run a simulation (based on Chinese readers' data) that would mimic, as closely as possible, the analysis provided by Perea et al. (2018). Perea et al. collected the correct response rates of participants for 4 categories (23 conditions) of five-letter Thai pseudowords in a two-alternative forced-choice task and used the error rate data to constrain the parameters of Gómez et al.'s overlap model. Similarly, I analysed the RT data of Chinese participants collected the Chinese masked lexical decision (LDT) experiments from Chapter 2. The assumption I made was that in the masked priming LDT task, the priming effect can provide is a measure of the orthographic similarity between the prime and target, which can then be represented in the overlap score between the prime and target in the model calculations. I then used the same method as Gómez et al. and Perea et al. to calculate the overlap score and constrain the model.

The R software and its general-purpose optimization function which is based on the Nelder–Mead algorithm (Nocedal & Wright, 1999) were used to adjust and constrain the parameters of the overlap model. The averaged RT data were from 8 prime conditions for four-character Chinese words (repetition, character 2/3 transposed, character 1/4 transposed, backward, character 2/3 substituted, character 2/3 substituted and 1/4 transposed, character 1/4 substituted and 2/3 transposed, unrelated) with all the other experimental settings being identical in the various conditions. I transformed the RT data linearly into the range 0 to 1, with the transformed value of the repetition condition (which was the smallest) being 0 and the transformed valued of unrelated condition (which was the longest) being 1. The parameters of overlap model we got after fitting the model showed that the coding flexibilities (overlap scores) of different positions in four-character Chinese words varies less across positions and, therefore, had a different pattern from English and Thai. That is, the position coding scores did seem to be somewhat less constrained in Chinese. For example, the position coding precision for the first and fourth character were at the same level (see Figure 6) and were only slightly stronger than that for the second and third character whereas in English the position coding precision for the first letter is substantially higher. Overall, the overlap score between backward prime and its target was 0.45, which does suggest that the model would be able to predict some backward priming effects in Chinese. However, because our results were based on RT data in a task that was different from Perea et al.'s (2018) and Gomez et al.'s (2008) and we only had 8 conditions in total, caution need to be exercized when comparing the Chinese results with the English or Thai results. The model does, however, seem to have some promise. Nonetheless, if one wants to create a Chinese orthographic model based on these types of principles, one will need to collect data from many more conditions and participants.

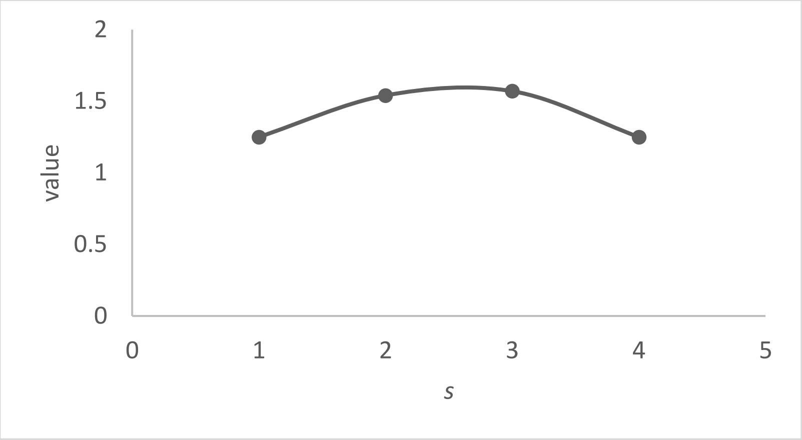


Figure 6: Values of the s parameter of the overlap model for Chinese in each of the letter positions: 1 to 4

It is important, of course, to note some of the limitations of this present research. First of all, only behavioural methods were used. It may be of some benefit to use neuroscience methods to further explore these issues, such as event-related potential (ERP) technology which has better time resolution than traditional behavioural methods. Holcomb and Grainger (2007) and Grainger, Kiyonaga and Holcomb (2006) have suggested, for example, that there are two important components in ERP data. The first component is the N250 component which they suggested is sensitive to the nature of the orthographic representations of the presented stimuli, representations that map onto phonological and whole word representations, essentially, what can be thought of as the orthographic code. The second component, the N400 component, is relevant to the mapping of whole word representations onto meaning. Orthographic processing, therefore, is indexed by what mainly happens in the early time window ranging from 150 ms to 250 ms, whereas higher-level processing is mainly indexed by what happens in the time window ranging from 250 ms to 400 ms. Presumably, if the Chinese backward priming effect is due to orthographic coding, one would expect to find evidence of that pattern in the early window (e.g, a N250 component would be different for orthographically related conditions and orthographically unrelated conditions) in the ERP data.

It would, of course, also be important to gain a deeper understanding of this apparent letter position coding difference between English and Chinese readers (i.e., to examine my Chinese character position free processing hypothesis more closely). First, there is the question of whether the backward priming effects are merely a Chinese phenomenon, will this effect show up in other languages besides Chinese? Initially, it would be interesting to try to replicate this backward priming effect in different languages, for example, Japanese (using logographic Kanji and syllabic Kana), Arabic (a Semitic script) and Spanish (which, like English, uses the Roman alphabet).

According to perceptual learning accounts, people most familiar with processing words in a backward, as well as forward, orientation, should show the largest priming effects. As we all know, unlike most other languages, Arabic is written from right to left. Based on the fact that English readers do not show backward priming effects whereas Chinese readers can, the perceptual learning account could imagine that this effect may only be due to Chinese readers having had enough experience in reading text presented from right-to-left whereas English readers are totally unfamiliar with backward oriented scripts. As Arabic text is written from right to left, Arabic readers woud have had more experience in reading right-to-left text than Chinese readers. If the perceptual learning process of reading right-to-left words is crucial for allowing Chinese readers to produce backward priming effects, Arabic-English bilinguals should produce a backward priming effect (i.e., a priming effect when the prime is written in an unfamiliar left-to-right orientation) with English stimuli. If the results do not turn out in that way, presumably there is some other factor besides experience that leads to the significant backward priming effect. For example, according to my account because there are more characters in Chinese and Japanese than in Arabic and English, Chinese and Japanese words have a limited number of orthographic neighbours and anagrams, meaning that there would be less orthographic constraint and less lexical competition in Chinese and Japanese than in Arabic and English. It may be, therefore, that it is these characteristics that lead to backward priming effects, that is, the orthographic coding flexibility is shaped by each languages' essential characteristics (note, however, that a similar argument has been made by proponents of perceptual learning accounts, e.g., Lally, Taylor, Lee & Rastle, 2019, and Lerner, Armstrong & Frost, 2014).

It will also be interesting to examine the impact of a having Chinese as a reader's first language on orthographic coding in a second language if that language is alphabetic. According to my account, Chinese bilinguals may have more flexibility in letter position coding when reading their second language (English) due to how they learned to read Chinese. If so, one might also expect to see a backward priming priming effect when Chinese-English bilinguals read English words. That is, because they have more flexibility in their first language, they might also apply this flexibile coding to reading in their second language. If so, one could argue that when they are processing their second language, the orthographic code of Chinese-English bilinguals is not the same as that of English L1 readers. In general, my next step will be an exploration of language differences in orthographic coding with an eye toward understanding the impact of these differences for models of orthographic coding.

5.2 Overall Conclusion

Visuospatial orientation of words themselves does not influence form priming effects in English (Chapter 4) while in logographic scripts like Chinese the visual orientation and ordering of the letters themselves does not influence priming effects. Such results support abstract letter/character unit accounts of form priming effects while failing to support most perceptual learning accounts. Further, these results also suggest that Chinese readers have more flexible (i.e., less precise) letter position coding than English readers, as shown by this fact that Chinese readers can produce extreme transposition priming effects whereas English readers cannot, effects that appear to be essentially orthographically-based. These results pose new challenges to existing orthographic coding models, which may need to be addressed by adopting assumptions of the sort reflected in my Chinese character position free processing hypothesis.

References

Amano, N., & Kondo, K. (2003). NTT detabesu shirizu: Nihongo no goi-tokusei, Dai 2-ki CD-ROM-ban [NTT database series: Lexical properties of Japanese, Vol. 2, CD-ROM version]. Tokyo, Japan: Sanseido.

Adelman, J. S. (2011). Letters in time and retinotopic space. *Psychological Review*, *118*(4), 570–582. https://doi.org/http://dx.doi.org/10.1037/a0024811

Amano N, & Kondo K. (2003). *NTT detabesu shirizu: Nihongo no goi-tokusei, Dai 2-ki CD-ROM-ban [NTT database series: Lexical properties of Japanese, Vol. 2, CD-ROM version]*. Tokyo, Japan: Sanseido.

Baayen, R. H. (2008). Analyzing linguistic data: A practical introduction to statistics using R. In *Processing*. Retrieved from http://www.sfs.uni-tuebingen.de/~hbaayen/publications/baayenCUPstats.pdf

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language*, *59*(4), 390–412. https://doi.org/10.1016/j.jml.2007.12.005

Balota, D. A., Aschenbrenner, A. J., & Yap, M. J. (2013). Additive effects of word frequency and stimulus quality: The influence of trial history and data transformations. *Journal of Experimental Psychology: Learning Memory and Cognition*, *39*(5), 1563–1571. https://doi.org/10.1037/a0032186

Balota, D. A., Yap, M. J., Cortese, M. J., Hutchison, K. A., Kessler, B., Loftis, B., … Treiman, R. (2007). The english lexicon project. *Behavior Research Methods*, *39*(3), 445–459. https://doi.org/10.3758/BF03193014

Balota, D. A., Yap, M. J., Cortese, M. J., & Watson, J. M. (2008). Beyond mean response latency: Response time distributional analyses of semantic priming. *Journal of Memory and Language*, *59*(4), 495–523. https://doi.org/10.1016/j.jml.2007.10.004

Baron, J., & Strawson, C. (1976). Use of orthographic and word-specific knowledge in reading words aloud. *Journal of Experimental Psychology: Human Perception and Performance*, *2*(3), 386–393.

Barr, D. J. (2013). Random effects structure for testing interactions in linear mixed-effects models. *Frontiers in Psychology*, *4*, 328. https://doi.org/10.3389/fpsyg.2013.00328

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Berent, I. (1997). Phonological priming in the lexical decision task: regularity effects are not necessary evidence for assembly. *Journal of Experimental Psychology. Human Perception and Performance*, *23*(6), 1727–1742. https://doi.org/10.1037/0096-1523.23.6.1727

Bolker, B. (2018). *Glmm faq*. Retrieved from https://bbolker.github.io/%0Amixedmodels-misc/glmmFAQ.html

Brysbaert, M., & Stevens, M. (2018). Power analysis and effect size in mixed effects models: A tutorial. *Journal of Cognition*, *1*(1), 9. https://doi.org/10.5334/joc.10

Bub, D. N., & Lewine, J. (1988). Different modes of word recognition in the left and right visual fields. *Brain and Language*, *33*(1), 161–188. https://doi.org/10.1016/0093-934X(88)90060-0

Cai, Q., & Brysbaert, M. (2010). SUBTLEX-CH: Chinese word and character frequencies based on film subtitles. *PLoS ONE*, *5*(6), e10729. https://doi.org/10.1371/journal.pone.0010729

Chang, C. H. C., Pallier, C., Wu, D. H., Nakamura, K., Jobert, A., Kuo, W. J., & Dehaene, S. (2015). Adaptation of the human visual system to the statistics of letters and line configurations. *NeuroImage*, *120*, 428–440. https://doi.org/10.1016/j.neuroimage.2015.07.028

Chen, H. C., & Tzeng, O. J. L. (1992). Character Recognition and Naming. In H. C. Chen & O. J. L. Tzeng (Eds.), *Language processing in Chinese* (pp. 3–93). Amsterdam: Elsevier Science.

Chen, Hsin-Chin, Yamauchi, T., Tamaoka, K., & Vaid, J. (2007). Homophonic and semantic priming of Japanese kanji words: A time course study. *Psychonomic Bulletin & Review*, *14*(1), 64–69. https://doi.org/https://doi.org/10.3758/BF03194029

Chen, Hsuan-Chih, & Shu, H. (2001). Lexical activation during the recognition of Chinese characters: Evidence against early phonological activation. *Psychonomic Bulletin & Review*, *8*(3), 511–518. https://doi.org/https://doi.org/10.3758/BF03196186

Cohen, L., Dehaene, S., Vinckier, F., Jobert, A., & Montavont, A. (2008). Reading normal and degraded words: Contribution of the dorsal and ventral visual pathways. *NeuroImage*, *40*(1), 353–366. https://doi.org/10.1016/j.neuroimage.2007.11.036

Coltheart, M., Davelaar, E., Jonasson, T., & Besner, D. (1977). Access to the internal lexicon. In S. Domic (Ed.), *Attention and Performance VI* (pp. 535–555). https://doi.org/10.1006/brln.2001.2475

Crepaldi, D., Rastle, K., Coltheart, M., & Nickels, L. (2010). 'Fell' primes 'fall', but does 'bell' prime 'ball'? Masked priming with irregularly- inflected primes. *Journal of Memory and Language*, *63*(1), 83–99. https://doi.org/10.1016/j.jml.2010.03.002

Crepaldi, D., Rastle, K., Davis, C. J., & Lupker, S. J. (2013). Seeing stems everywhere: Position-independent identification of stem morphemes. *Journal of Experimental Psychology: Human Perception and Performance*, *39*(2), 510–525. https://doi.org/10.1037/a0029713

Davis, C., Kim, J., & Forster, K. I. (2008). Being forward not backward: Lexical limits to masked priming. *Cognition*, *107*(2), 673–684. https://doi.org/10.1016/j.cognition.2007.07.016

Davis, Colin J., & Lupker, S. J. (2006). Masked inhibitory priming in English: Evidence for lexical inhibition. *Journal of Experimental Psychology: Human Perception and Performance*, *32*(3), 668–687. https://doi.org/10.1037/0096-1523.32.3.668

Davis, Colin John. (1999). *The self-organising lexical acquisition and recognition (SOLAR) model of visual word recognition.* University of New South Wales, Sydney, Australia.

Davis, Colin John. (2010). The spatial coding model of visual word identification. *Psychological Review*, *117*(3), 713–758. https://doi.org/10.1037/a0019738

Dehaene, S., Cohen, L., Sigman, M., & Vinckier, F. (2005). The neural code for written words: A proposal. *Trends in Cognitive Sciences*, *9*(7), 335–341. https://doi.org/10.1016/j.tics.2005.05.004

Diependaele, K., Sandra, D., & Grainger, J. (2009). Semantic transparency and masked morphological priming: The case of prefixed words. *Memory and Cognition*, *37*(6), 895–908. https://doi.org/10.3758/MC.37.6.895

Drews, E., & Zwitserlood, P. (1995). Morphological and orthographic similarity in visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance*, *21*(5), 1098–1116. https://doi.org/10.1037/0096-1523.21.5.1098

Duñabeitia, J. A., Dimitropoulou, M., Grainger, J., Hernández, J. A., & Carreiras, M. (2012). Differential sensitivity of letters, numbers, and symbols to character transpositions. *Journal of Cognitive Neuroscience*, *24*(7), 1610–1624. https://doi.org/10.1162/jocn_a_00180

Duñabeitia, J. A., Kinoshita, S., Carreiras, M., & Norris, D. (2011). Is morpho-orthographic decomposition purely orthographic? Evidence from masked priming in the same-different task. *Language and Cognitive Processes*, *26*(4–6), 509-529. https://doi.org/10.1080/01690965.2010.499215

Ferrand, L., & Grainger, J. (1992). Phonology and orthography in visual word recognition: Evidence from masked non-word priming. *The Quarterly Journal of Experimental Psychology Section A*, *45*(3), 353–372. https://doi.org/https://doi.org/10.1080/02724989208250619

Ferrand, L., & Grainger, J. (1993). The time course of orthographic and phonological code activation in the early phases of visual word recognition. *Bulletin of the Psychonomic Society*, *31*(2), 119–122. https://doi.org/10.3758/BF03334157

Forster, K. I., & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *10*(4), 680–698. https://doi.org/10.1037/0278-7393.10.4.680

Fox, J., & Weisberg, S. (2016). car: Companion to applied regression. *R Package Version 2.1-2*. Retrieved from http://socserv.socsci.mcmaster.ca/jfox/Books/Companion

García-Orza, J., Pera, M., & Muñoz, S. (2010). Are transposition effects specific to letters? *Quarterly Journal of Experimental Psychology*, *63*(8), 1603–1618. https://doi.org/10.1080/17470210903474278

García-Orza, J., Perea, M., & Estudillo, A. (2011). Masked transposition effects for simple versus complex nonalphanumeric objects. *Attention, Perception, and Psychophysics*, *73*(8), 2573–2582. https://doi.org/10.3758/s13414-011-0206-7

Gil-López, C., Perea, M., Moret-Tatay, C., & Carreiras, M. (2011). Can masked priming effects be obtained with handwritten words? *Attention, Perception, & Psychophysics*, *73*(6), 1643–1649. https://doi.org/https://doi.org/10.3758/s13414-011-0174-y

Gómez, P., Ratcliff, R., & Perea, M. (2008). The overlap model: A model of letter position coding. Psychological. *Psychological Review, 115*(3), 577–600. https://doi.org/10.1037/a0012667

Grainger, J. (2016). Orthographic processing and reading. *Visible Language*, *50*(2), 80.

Grainger, J. (2018). Orthographic processing: A ‘mid-level’vision of reading: The 44th Sir Frederic Bartlett Lecture. *Quarterly Journal of Experimental Psychology, 71*(2), 335–359. https://doi.org/https://doi.org/10.1080/17470218.2017.1314515

Grainger, J., Dufau, S., & Ziegler, J. C. (2016). A vision of reading. *Trends in Cognitive Sciences*, *20*(3), 171–179. https://doi.org/https://doi.org/10.1016/j.tics.2015.12.008

Grainger, J., & Ferrand, L. (1994). Phonology and orthography in visual word recognition: Effects of masked homophone primes. *Journal of Memory and Language*, *33*(2), 218–233. https://doi.org/https://doi.org/10.1006/jmla.1994.1011

Grainger, J., Granier, J. P., Farioli, F., Van Assche, E., & Van Heuven, W. J. B. (2006). Letter position information and printed word perception: The relative-position priming constraint. *Journal of Experimental Psychology: Human Perception and Performance, 32*(4), 865–884. https://doi.org/10.1037/0096-1523.32.4.865

Grainger, J., & Holcomb, P. (2007). Neural Constraints on a Functional Architecture for Word Recognition. *L’anne´e Psychologique*, *107*, 623– 658. https://doi.org/10.1093/acprof:oso/9780195300369.003.0001

Grainger, J., & Holcomb, P. J. (2009). Watching the word go by: On the time-course of component processes in visual word recognition. *Language and Linguistics Compass*, *3*(1), 128–156. https://doi.org/https://doi.org/10.1111/j.1749-818X.2008.00121.x

Grainger, J., & Jacobs, A. M. (1993). Masked Partial-Word Priming in Visual Word Recognition: Effects of Positional Letter Frequency. *Journal of Experimental Psychology: Human Perception and Performance*, *19*, 951–964. https://doi.org/10.1037/0096-1523.19.5.951

Grainger, J., & Jacobs, A. M. (1996). Orthographic processing in visual word recognition: A multiple read-out model. *Psychological Review*, *103*(3), 518–565. https://doi.org/10.1037/0033-295X.103.3.518

Grainger, J., Kiyonaga, K., & Holcomb, P. J. (2006). The time course of orthographic and phonological code activation. *Psychological Science*, *17*(12), 1021–1026. https://doi.org/10.1111/j.1467-9280.2006.01821.x

Grainger, J., & Van Heuven, W. J. B. (2003). Modeling letter position coding in printed word perception. In P. Bonin (Ed.), *The mental lexicon*. Retrieved from http://sites.univ-provence.fr/wlpc/pagesperso/grainger/CHAPTERS/Grainger&van-Heuven03.pdf

Gu, J., & Li, X. (2015). The effects of character transposition within and across words in Chinese reading. *Attention, Perception and Psychophysics*, *77*(1), 272–281. https://doi.org/10.3758/s13414-014-0749-5

Gu, J., Li, X., & Liversedge, S. P. (2015). Character order processing in Chinese reading. *Journal of Experimental Psychology: Human Perception and Performance*, *41*(1), 127–137. https://doi.org/10.1037/a0038639

Guerrera, C., & Forster, K. (2008). Masked form priming with extreme transposition. *Language* *and Cognitive Processes*, *23*(1), 117–142. https://doi.org/10.1080/01690960701579722

Holcomb, P. J., & Grainger, J. (2007). Exploring the temporal dynamics of visual word recognition in the masked repetition priming paradigm using event-related potentials. *Brain Research*, *1180*(1), 39–58. https://doi.org/10.1016/j.brainres.2007.06.110

Holyk, G. G., & Pexman, P. M. (2004). The elusive nature of early phonological priming effects: Are there individual differences? *Brain and Language*, *90*(1–3), 353–367. https://doi.org/https://doi.org/10.1016/S0093-934X(03)00447-4

Huang, J. T., & Liu, I. M. (1978). Effects of two-character word frequency, meaningfulness, and imagery on paired-word learning. *Chinese Journal of Psychology*, *20*, 1–4.

Jeffreys, H. (1961). *Theory of probability* (Third Edit). Oxford: The Clarendon Press.

Kinoshita, S., & Norris, D. (2009). Transposed-Letter Priming of Prelexical Orthographic Representations. *Journal of Experimental Psychology: Learning Memory and Cognition*, *35*(1), 1–18. https://doi.org/10.1037/a0014277

Kinoshita, S., & Norris, D. (2010). Masked priming effect reflects evidence accumulated by the prime. *Quarterly Journal of Experimental Psychology*, *63*(1), 194–204. https://doi.org/10.1080/17470210902957174

Kinoshita, S., Norris, D., & Siegelman, N. (2012). Transposed-letter priming effect in Hebrew in the same-different task. *Quarterly Journal of Experimental Psychology*, *65*(7), 1296-1305. https://doi.org/10.1080/17470218.2012.655749

Kinoshita, S., Schubert, T., & Verdonschot, R. G. (2019). Allograph priming is based on abstract letter identities: Evidence from Japanese kana. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *45*(1), 183–190. https://doi.org/10.1037/xlm0000563

Koriat, A., & Norman, J. (1985). Reading rotated words. *Journal of Experimental Psychology: Human Perception and Performance*, *11*(4), 490–508.

Ktori, M., Kingma, B., Hannagan, T., Holcomb, P. J., & Grainger, J. (2015). On the time-course of adjacent and non-adjacent transposed- letter priming. *Journal of Cognitive Psychology*, *26*(5), 491–505. https://doi.org/10.1080/20445911.2014.922092

Lally, C., Taylor, J. S. H., Lee, C. H., & Rastle, K. (2019). Shaping the precision of letter position coding by varying properties of a writing system. *Language, Cognition and Neuroscience*, 1–9. https://doi.org/https://doi.org/10.1080/23273798.2019.1663222

Lavidor, M. (2002). An examination of the lateralized abstractive/form specific model using MiXeD-CaSe primes. *Brain and Cognition*, *48*(2–3), 413–417.

Legge, G. E., Ahn, S. J., Klitz, T. S., & Luebker, A. (1997). Psychophysics of reading - XVI. The visual span in normal and low vision. *Vision Research*, *37*(14), 1999–2010. https://doi.org/10.1016/S0042-6989(97)00017-5

Lenth, R V. (2018). *emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.1*. Retrieved from https://cran.r-project.org/%0Apackageemmeans%0D

Lenth, Russell V. (2016). Least-Squares Means: The R Package lsmeans. *Journal of Statistical*

Software, *69*(1), 1–33. https://doi.org/10.18637/jss.v069.i01

Lerner, I., Armstrong, B. C., & Frost, R. (2014). What can we learn from learning models about sensitivity to letter-order in visual word recognition? *Journal of Memory and Language*, *77*, 40–58. https://doi.org/https://doi.org/10.1016/j.jml.2014.09.002

Lété, B., & Fayol, M. (2013). Substituted-letter and transposed-letter effects in a masked priming paradigm with French developing readers and dyslexics. *Journal of Experimental Child Psychology*, *114*(1), 47–62. https://doi.org/10.1016/j.jecp.2012.09.001

Levy, R. (2014). Using R formulae to test for main effects in the presence of higher-order interactions. *ArXiv Preprint ArXiv:1405.2094*. Retrieved from https://arxiv.org/pdf/1405.2094.pdf

Li, X., Rayner, K., & Cave, K. R. (2009). On the segmentation of Chinese words during reading. *Cognitive Psychology*, *58*(4), 525–552. https://doi.org/10.1016/j.cogpsych.2009.02.003

Lo, S., & Andrews, S. (2015). To transform or not to transform: using generalized linear mixed models to analyse reaction time data. *Frontiers in Psychology*, *30*(6), 1171. https://doi.org/10.3389/fpsyg.2015.01171

Lupker, S. J., Nakayama, M., & Perea, M. (2015). Is there phonologically based priming in the same-different task? Evidence from Japanese-English bilinguals. *Journal of Experimental Psychology: Human Perception and Performance*, *41*(5), 1281–1299. https://doi.org/10.1037/xhp0000087

Lupker, S. J., Nakayama, M., & Yoshihara, M. (2018). *Phonologically-Based Priming in the Same-Different Task With L1 Readers*. *44*(8), 1317-1324. https://doi.org/http://dx.doi.org/10.1037/xlm0000515

Lupker, S. J., Perea, M., & Nakayama, M. (2015). Non-cognate translation priming effects in the same–different task: evidence for the impact of “higher level” information. *Language, Cognition and Neuroscience*, *30*(7), 781–795. https://doi.org/https://doi.org/10.1080/23273798.2015.1015430

Massol, S., Duñabeitia, J. A., Carreiras, M., & Grainger, J. (2013). Evidence for Letter-Specific Position Coding Mechanisms. *PLoS ONE*, *8*(7), e68460. https://doi.org/10.1371/journal.pone.0068460

Mattingly, I. G. (1992). Linguistic awareness and orthographic form. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 11–26). Amsterdam: Elsevier Science.

McClelland, J. L., & Rumelhart, D. E. (1981). An Interactive Activation Model of Context Effects in Letter Perception: Part I. An Account of Basic Findings. *Readings in Cognitive Science: A Perspective from Psychology and Artificial Intelligence*, *88*(5), 375–407. https://doi.org/10.1037/0033-295X.88.5.375

Morris, A. L., & Still, M. L. (2012). Orthographic similarity: The case of “reversed anagrams”. *Memory & cognition*, *40*(5), 779-790. http://dx.doi.org/10.3758/s13421-012-0183-7

New, B., Brysbaert, M., Segui, J., Ferrand, L., & Rastle, K. (2004). The processing of singular and plural nouns in French and English. *Journal of Memory and Language*, *51*(4), 568–

585. https://doi.org/10.1016/j.jml.2004.06.010

Norris, D. (2006). The Bayesian reader: Explaining word recognition as an optimal bayesian decision process. *Psychological Review*, *113*(2), 327–357. https://doi.org/10.1037/0033-295X.113.2.327

Norris, D., & Kinoshita, S. (2008). Perception as Evidence Accumulation and Bayesian Inference: Insights From Masked Priming. *Journal of Experimental Psychology: General*, *137*(3), 434–455. https://doi.org/10.1037/a0012799

Norris, D., & Kinoshita, S. (2012). Reading through a noisy channel: Why there's nothing special about the perception of orthography. *Psychological Review*, *119*(3), 517–545. https://doi.org/10.1037/a0028450

Norris, D., Kinoshita, S., & van Casteren, M. (2010). A stimulus sampling theory of letter identity and order. *Journal of Memory and Language*, *62*(3), 254–271. https://doi.org/10.1016/j.jml.2009.11.002

Perea, M., Jiménez, M., & Gómez, P. (2014). A challenging dissociation in masked identity priming with the lexical decision task. *Acta Psychologica*, *148*, 130–135. https://doi.org/10.1016/j.actpsy.2014.01.014

Perea, M., & Lupker, S. J. (2003a). Does jugde activate COURT? Transposed-letter similarity effects in masked associative priming. *Memory and Cognition*, *31*(6), 829–841. https://doi.org/10.3758/BF03196438

Perea, M., & Lupker, S. J. (2003b). Transposed-letter confusability effects in masked form priming. In S. Kinoshita & S. J. Lupker (Eds.), *Masked Priming: The State of the Art* (pp. 97–120). https://doi.org/10.4324/9780203502846

Perea, M., & Lupker, S. J. (2004). Can CANISO activate CASINO? Transposed-letter similarity effects with nonadjacent letter positions. *Journal of Memory and Language*, *51*(2), 231–246. https://doi.org/10.1016/j.jml.2004.05.005

Perea, M., Marcet, A., & Fernández-López, M. (2018). Does letter rotation slow down orthographic processing in word recognition? *Psychonomic Bulletin and Review*, *25*(6), 2295–2300. https://doi.org/https://doi.org/10.3758/s13423-017-1428-z

Perea, M., Moret-Tatay, C., & Carreiras, M. (2011). Facilitation versus inhibition in the masked priming same–different matching task. *The Quarterly Journal of Experimental Psychology*, *64*(10), 2065–2079. https://doi.org/https://doi.org/10.1080/17470218.2011.582131

Perea, M., Nakatani, C., & van Leeuwen, C. (2011). Transposition effects in reading Japanese Kana: Are they orthographic in nature? *Memory and Cognition*, *39*(4), 700–707. https://doi.org/10.3758/s13421-010-0052-1

Perea, M., Nakayama, M., & Lupker, S. J. (2017). Alternating-script priming in Japanese: Are Katakana and Hiragana characters interchangeable? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *43*(7), 1140–1146. https://doi.org/http://dx.doi.org/10.1037/xlm0000365

Perea, M., & Pérez, E. (2009). Beyond alphabetic orthographies: The role of form and phonology in transposition effects in Katakana. *Language and Cognitive Processes*, *24*(1), 67–88. https://doi.org/10.1080/01690960802053924

Perea, M., Vergara-Martínez, M., & Gomez, P. (2015). Resolving the locus of cAsE aLtErNaTiOn effects in visual word recognition: Evidence from masked priming. *Cognition*, *142*, 39–43. https://doi.org/10.1016/j.cognition.2015.05.007

Perea, M., Winskel, H., & Gómez, P. (2017). How orthographic-specific characteristics shape letter position coding: The case of Thai script. *Psychonomic Bulletin & Review*, 1–7. https://doi.org/10.3758/s13423-017-1279-7

Perfetti, C. A., & Liu, Y. (2006). Reading Chinese characters: Orthography, phonology, meaning, and the lexical constituency model. In P. Li, L. H. Tan, E. Bates, & O. J. L. Tzeng (Eds.), *Handbook of East Asian psycholinguistics* (pp. 225–236). New York, NY: Cambridge University Press.

Perfetti, C. A., & Tan, L. H. (1998). The time course of graphic, phonological, and semantic activation in Chinese character identification. *Journal of Experimental Psychology: Learning Memory and Cognition*, *24*(1), 101–118. https://doi.org/10.1037/0278-7393.24.1.101

Perfetti, C. A., & Zhang, S. (1995). Very early phonological activation in Chinese reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*(1), 24–33. https://doi.org/http://dx.doi.org/10.1037/0278-7393.21.1.24

Perfetti, C. A., Zhang, S., & Berent, I. (1992). Reading in english and chinese: Evidence for a “Universal” phonological principle. *Advances in Psychology*, *94*, 227–248. https://doi.org/10.1016/S0166-4115(08)62798-3

Qu, Q., Damian, M. F., & Li, X. (2016). Phonology contributes to writing: evidence from a masked priming task. *Language, Cognition and Neuroscience*, *31*(2), 251–264. https://doi.org/10.1080/23273798.2015.1091086

R Core Team. (2015). *R: A Language and Environment for Statistical Computing*, Vol. 1, p. 63. Retrieved from https://cran.r-project.org/doc/manuals/r-release/R-ints.html

Rastle, K., & Brysbaert, M. (2006). Masked phonological priming effects in English: Are they real? Do they matter? *Cognitive Psychology*, *53*(2), 97–145. https://doi.org/10.1016/j.cogpsych.2006.01.002

Rastle, K., & Davis, M. H. (2008). Morphological decomposition based on the analysis of orthography. *Language and Cognitive Processes*, *23*(7–8), 942–971. https://doi.org/https://doi.org/10.1080/01690960802069730

Rastle, K., Davis, M. H., & New, B. (2004). The broth in my brother’s brothel: Morpho-orthographic segmentation in visual word recognition. *Psychonomic Bulletin & Review*, *11*(6), 1090–1098. https://doi.org/https://doi.org/10.3758/BF03196742

Risko, E. F., Medimorec, S., Chisholm, J., & Kingstone, A. (2014). Rotating with rotated text: A natural behavior approach to investigating cognitive offloading. *Cognitive Science*, *38*(3), 537–564. https://doi.org/https://doi.org/10.1111/cogs.12087

Schiller, N. O. (1999). Masked syllable priming of English nouns. *Brain and Language*, *68*(1–2), 300–305. https://doi.org/10.1006/brln.1999.2109

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime: User’s guide*. Pittsburgh, PA:

Psychology Software Tools.

Schoonbaert, S., & Grainger, J. (2004). Letter position coding in printed word perception: Effects of repeated and transposed letters. *Language and Cognitive Processes, 19*(3), 333–367. https://doi.org/10.1080/01690960344000198

Schubert, T., Gawthrop, R., & Kinoshita, S. (2018). Evidence for cross-script abstract identities in learners of Japanese kana. *Memory & Cognition*, *46*(6), 1010–1021. https://doi.org/https://doi.org/10.3758/s13421-018-0818-4

Shen, D., & Forster, K. I. (1999). Masked phonological priming in reading Chinese words depends on the task. *Language and Cognitive Processes*, *14*(5–6), 429–459. https://doi.org/https://doi.org/10.1080/016909699386149

Singmann, H., & Kellen, D. (2017). An Introduction to Mixed Models for Experimental Psychology. In D. Spieler & E. Schumacher (Eds.), *New Methods in Neuroscience and Cognitive Psychology* (pp. 1–39). Retrieved from https://cran.r-project.org/web/packages/afex/vignettes/introduction-mixed-models.pdf

Taft, M., Liu, Y., & Zhu, X. (1999). *Reading Chinese script: A cognitive analysis*. Mahwah, NJ: Lawrence Erlbaum.

Taft, M., & Nguyen-Hoan, M. (2010). A sticky stick? The locus of morphological representation in the lexicon. *Language and Cognitive Processes*, *25*(2), 277–296. https://doi.org/10.1080/01690960903043261

Taft, M., & Zhu, X. (1997a). Submorphemic processing in reading Chinese. *Journal of Experimental Psychology: Learning Memory and Cognition*, *23*(3), 761–775. https://doi.org/10.1037/0278-7393.23.3.761

Taft, M., & Zhu, X. (1997b). Using masked priming to examine lexical storage of Chinese compound words. In H. C. Chen (Ed.), *Cognitive processing of Chinese and related Asian languages* (pp. 233–241). The Chinese University Press, Hong Kong.

Taft, M., Zhu, X., & Peng, D. (1999). Positional Specificity of Radicals in Chinese Character Recognition. *Journal of Memory and Language*, *40*(4), 498–519. https://doi.org/10.1006/jmla.1998.2625

Tse, C.-S., Yap, M. J., Chan, Y.-L., Sze, W. P., Shaoul, C., & Lin, D. (2017). The Chinese Lexicon Project: A megastudy of lexical decision performance for 25,000+ traditional Chinese two-character compound words. *Behavior Research Methods*, *49*(4), 1503–1519. https://doi.org/https://doi.org/10.3758/s13428-016-0810-5

Van den Bussche, E., Van den Noortgate, W., & Reynvoet, B. (2009). Mechanisms of Masked Priming: A Meta-Analysis. *Psychological Bulletin*, *135*(3), 452–477. https://doi.org/10.1037/a0015329

Van Selst, M., & Jolicoeur, P. (1994). A Solution to the Effect of Sample Size on Outlier Elimination. *The Quarterly Journal of Experimental Psychology*, *47*(3), 631–650. https://doi.org/10.1080/14640749408401131

Velan, H., & Frost, R. (2009). Letter-transposition effects are not universal: The impact of transposing letters in Hebrew. *Journal of Memory and Language*, *61*(3), 285–302. https://doi.org/10.1016/j.jml.2009.05.003

Vergara-Martínez, M., Perea, M., Gómez, P., & Swaab, T. Y. (2013). ERP correlates of letter identity and letter position are modulated by lexical frequency. *Brain and Language, 125*(1), 11–27. https://doi.org/10.1016/j.bandl.2012.12.009

Wagenmakers, E. J. (2007). A practical solution to the pervasive problems of p values. *Psychonomic Bulletin and Review, 14*(5), 779–804. https://doi.org/10.3758/BF03194105

Wang, W. S. Y. (1973). The Chinese language. *Scientific American*, *228*(2), 50–63.

Whitney, C, & Marton, Y. (2013). The SERIOL2 Model of Orthographic Processing. *Online Submission*, 1–76. Retrieved from http://eric.ed.gov/?id=ED543279

Whitney, Carol. (2001). How the brain encodes the order of letters in a printed word: The SERIOL model and selective literature review. *Psychonomic Bulletin and Review, 8*(2), 221–243. https://doi.org/10.3758/BF03196158

Whitney, Carol. (2002). An explanation of the length effect for rotated words. *Cognitive Systems Research*, *3*(1), 113–119.

Whitney, Carol. (2018). When serial letter processing implies a facilitative length effect. *Language, Cognition and Neuroscience, 33*(5), 659–664. https://doi.org/10.1080/23273798.2017.1404115

Witzel, N., Qiao, X., & Forster, K. (2011). Transposed letter priming with horizontal and vertical text in Japanese and English readers. *Journal of Experimental Psychology: Human Perception and Performance*, *37*(3), 914–920. https://doi.org/10.1037/a0022194

Wong, A. W. K., Wu, Y., & Chen, H. C. (2014). Limited role of phonology in reading Chinese two-character compounds: Evidence from an ERP study. *Neuroscience*, *256*, 342–351. https://doi.org/10.1016/j.neuroscience.2013.10.035

Wu, Y., Tsang, Y. K., Wong, A. W. K., & Chen, H. C. (2017). The processing of homographic morphemes in Chinese: an ERP study. *Language, Cognition and Neuroscience, 32*(1), 102–116. https://doi.org/10.1080/23273798.2016.1227857

Yang, H., Chen, J., Spinelli, G., & Lupker, S. J. (2019). The impact of text orientation on form priming effects in four-character Chinese words. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *45*(8), 1511–1526. https://doi.org/http://dx.doi.org/10.1037/xlm0000655

Yang, H., Jared, D., Perea, M., & Lupker, S. J. (2019). *Letter coding flexibility in bilinguals*. Waterloo:ON: The annual meeting of the Canadian Society for Brain, Behaviour, and Cognitive Science.

Yang, H., & Lupker, S. J. (2019). Does letter rotation decrease transposed letter priming effects? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, Advance online publication. https://doi.org/10.1037/xlm0000697

Yang, H., Hino, Y., Chen, J., Yoshiharo, M., Nakayama, M., Xue, J. & Lupker, S. J. (2020). The Origins of Backward Priming Effects in Logographic Scripts for Four-Character Words. *Journal of Memory and Language 113,* 104107.

Yang, J. (2013). Preview effects of plausibility and character order in reading Chinese transposed words: Evidence from eye movements. *Journal of Research in Reading, 36*(SUPPL.1), 18–34. https://doi.org/10.1111/j.1467-9817.2013.01553.x

Yoshihara, M., Nakayama, M., Verdonschot, R. G., & Hino, Y. (2017). The phonological unit of Japanese Kanji compounds: A masked priming investigation. *Journal of Experimental Psychology: Human Perception and Performance*, *43*(7), 1303–1328. https://doi.org/http://dx.doi.org/10.1037/xhp0000374

You, W., Zhang, Q., & Verdonschot, R. G. (2012). Masked Syllable Priming Effects in Word and Picture Naming in Chinese. *PLoS ONE*, *7*(10), e46595. https://doi.org/10.1371/journal.pone.0046595

Zhang, B., & Peng, D. (1992). Decomposed Storage in the Chinese Lexicon. *Advances in Psychology*, *90*(C), 131–149. https://doi.org/10.1016/S0166-4115(08)61890-7

Zhou, X., & Marslen-Wilson, W. (1994). Words, morphemes and syllables in the Chinese mental lexicon. *Language and Cognitive Processes*, *9*(3), 393–422. https://doi.org/https://doi.org/10.1080/01690969408402125

Zhou, X., & Marslen-Wilson, W. (1995). Morphological structure in the Chinese mental lexicon. *Language and Cognitive Processes*, *10*(6), 545–600. https://doi.org/https://doi.org/10.1080/01690969508407114

Zhou, X., & Marslen-Wilson, W. (1999). Phonology, orthography, and semantic activation in reading Chinese. *Journal of Memory and Language*, *41*(4), 579–606. https://doi.org/https://doi.org/10.1006/jmla.1999.2663

Zhou, X., & Marslen-Wilson, W. D. (2009). Pseudohomophone effects in processing Chinese compound words. *Language and Cognitive Processes*, *24*(7–8), 1009–1038. https://doi.org/10.1080/01690960802174514

Zhou, X., Marslen-Wilson, W., Taft, M., & Shu, H. (1999). Morphology, orthography, and phonology in reading Chinese compound words. *Language and Cognitive Processes*, *14*(5–6), 525–565. https://doi.org/10.1080/016909699386185

Appendix A: Word Stimuli used in Chapter 2

All these stimuli were used in Experiment 2.1. The first half of the stimuli was used in Experiment 2.2. The first 100 stimuli were used in Experiment 2.3. The second half of the stimuli was used in Experiment 2.4. Note that the External SC primes were only used in Experiment 2.3.

	Condition				
Target	Repetition prime	TC prime	Classic SC prime	Unrelated prime	External SC prime
遮遮掩掩	遮遮掩掩	遮掩遮掩	遮救过掩	新奥尔良	救掩遮过
有所不同	有所不同	有不所同	有扑走同	总的来说	扑不所走
突如其来	突如其来	突其如来	突探古来	防毒面具	探其如古
完美无缺	完美无缺	完无美缺	完刹除缺	随时随地	刹无美除
了如指掌	了如指掌	了指如掌	了船标掌	引人注意	船指如标
出人意料	出人意料	出意人料	出违控料	时时刻刻	违意人控
微不足道	微不足道	微足不道	微对字道	深思熟虑	对足不字
有线电视	有线电视	有电线视	有眼泣视	每时每刻	眼电线泣
截然不同	截然不同	截不然同	截空款同	改头换面	空不然款
水深火热	水深火热	水火深热	水淡落热	独一无二	淡火深落
不值一提	不值一提	不一值提	不上仰提	精疲力竭	上一值仰
为时过早	为时过早	为过时早	为行义早	一举一动	行过时义
不省人事	不省人事	不人省事	不贯守事	种族主义	贯人省守
总而言之	总而言之	总言而之	总模品之	阿拉斯加	模言而品
精彩绝伦	精彩绝伦	精绝彩伦	精播秧伦	无时无刻	播绝彩秧
竭尽全力	竭尽全力	竭全尽力	竭违行力	指指点点	违全尽行
不切实际	不切实际	不实切际	不加小际	无足轻重	加实切小
第一夫人	第一夫人	第夫一人	第集力人	重归于好	集夫一力
自以为是	自以为是	自为以是	自信取是	别无选择	信为以取
情不自禁	情不自禁	情自不禁	情审规禁	福尔摩斯	审自不规
混为一谈	混为一谈	混一为谈	混矿化谈	天翻地覆	矿一为化
挺身而出	挺身而出	挺而身出	挺封制出	才华横溢	封而身制
电子游戏	电子游戏	电游子戏	电地态戏	事与愿违	地游子态
光明正大	光明正大	光正明大	光充用大	自言自语	充正明用
心不在焉	心不在焉	心在不焉	心逃陷焉	万无一失	逃在不陷
乳臭未干	乳臭未干	乳未臭干	乳脚瘤干	可不可以	脚未臭瘤
不久以后	不久以后	不以久后	不送谢后	精力充沛	送以久谢
无论如何	无论如何	无如论何	无监取何	胡言乱语	监如论取
前功尽弃	前功尽弃	前尽功弃	前战族弃	莫名其妙	战尽功族
从未有过	从未有过	从有未过	从木舢过	小题大做	木有未舢
胡说八道	胡说八道	胡八说道	胡增退道	为时已晚	增八说退
走投无路	走投无路	走无投路	走纠见路	摇摆不定	纠无投见
下定决心	下定决心	下决定心	下解缘心	愤世嫉俗	解决定缘
不可理喻	不可理喻	不理可喻	不作兵喻	未成年人	作理可兵
显而易见	显而易见	显易而见	显挂出见	不速之客	挂易而出
刮目相看	刮目相看	刮相目看	刮现下看	进退两难	现相目下
刀枪不入	刀枪不入	刀不枪入	刀拼开入	一丁点儿	拼不枪开
无动于衷	无动于衷	无于动衷	无下定衷	大名鼎鼎	下于动定

身不由己	身不由己	身由不己	身闭室己	滔滔不绝	闭由不室
乱七八糟	乱七八糟	乱八七糟	乱法议糟	一天到晚	法八七议
分道扬镳	分道扬镳	分扬道镳	分满船镳	脱胎换骨	满扬道船
尽管如此	尽管如此	尽如管此	尽录出此	激动人心	录如管出
远走高飞	远走高飞	远高走飞	远安年飞	一动不动	安高走年
辩护律师	辩护律师	辩律护师	辩游区师	无缘无故	游律护区
忍无可忍	忍无可忍	忍可无忍	忍互决忍	实话实说	互可无决
无理取闹	无理取闹	无取理闹	无祭化闹	换句话说	祭取理化
无懈可击	无懈可击	无可懈击	无据除击	圣诞老人	据可懈除
鸡尾酒会	鸡尾酒会	鸡酒尾会	鸡起缓会	哭哭啼啼	起酒尾缓
破门而入	破门而入	破而门入	破会礼入	焦头烂额	会而门礼
价值连城	价值连城	价连值城	价部领城	理所当然	部连值领
毫无用处	毫无用处	毫用无处	毫苦热处	遥遥领先	苦用无热
焕然一新	焕然一新	焕一然新	焕国士新	不为人知	国一然士
光彩照人	光彩照人	光照彩人	光人场人	格格不入	人照彩场
高速公路	高速公路	高公速路	高门岸路	除此之外	门公速岸
难以忘怀	难以忘怀	难忘以怀	难睡幕怀	偷偷摸摸	睡忘以幕
最高法院	最高法院	最法高院	最蛋碎院	说来话长	蛋法高碎
恐怖主义	恐怖主义	恐主怖义	恐椅窗义	全神贯注	椅主怖窗
袖手旁观	袖手旁观	袖旁手观	袖白棉观	长大成人	白旁手棉
并非如此	并非如此	并如非此	并献奏此	一劳永逸	献如非奏
多管闲事	多管闲事	多闲管事	多挂除事	此时此刻	挂闲管除
一塌糊涂	一塌糊涂	一糊塌涂	一高短涂	也就是说	高糊塌短
自掘坟墓	自掘坟墓	自坟掘墓	自放押墓	一无所知	放坟掘押
无所畏惧	无所畏惧	无畏所惧	无精略惧	西班牙语	精畏所略
心神不宁	心神不宁	心不神宁	心披下宁	墨西哥人	披不神下
光天化日	光天化日	光化天日	光阅件日	一声不吭	阅化天件
歇斯底里	歇斯底里	歇底斯里	歇补去里	成千上万	补底斯去
一路顺风	一路顺风	一顺路风	一协心风	鬼鬼祟祟	协顺路心
无所不能	无所不能	无不所能	无杀口能	合情合理	杀不所口
有史以来	有史以来	有以史来	有配数来	难以忍受	配以史数
无处不在	无处不在	无不处在	无惜重在	一网打尽	惜不处重
告一段落	告一段落	告段一落	告跨上落	毫不犹豫	跨段一上
好不容易	好不容易	好容不易	好偿赐易	筋疲力尽	偿容不赐
有鉴于此	有鉴于此	有于鉴此	有征者此	流言蜚语	征于鉴者
感激不尽	感激不尽	感不激尽	感微见尽	舒舒服服	微不激见
二氧化碳	二氧化碳	二化氧碳	二预位碳	甜言蜜语	预化氧位
难以启齿	难以启齿	难启以齿	难探起齿	千真万确	探启以起
千载难逢	千载难逢	千难载逢	千私诈逢	诺贝尔奖	私难载诈
束手无策	束手无策	束无手策	束知理策	心烦意乱	知无手理
白手起家	白手起家	白起手家	白官船家	恰到好处	官起手船
一无所获	一无所获	一所无获	一戴入获	无话可说	戴所无入
自作主张	自作主张	自主作张	自敬人张	不知所云	敬主作人
诸如此类	诸如此类	诸此如类	诸辞示类	成百上千	辞此如示
一如既往	一如既往	一既如往	一门债往	置身事外	门既如债
犹豫不决	犹豫不决	犹不豫决	犹战方决	全力以赴	战不豫方
毫无疑问	毫无疑问	毫疑无问	毫呈状问	鸡皮疙瘩	呈疑无状
直升飞机	直升飞机	直飞升机	直祝望机	虚张声势	祝飞升望
绝大多数	绝大多数	绝多大数	绝空漏数	天衣无缝	空多大漏
开门见山	开门见山	开见门山	开籍著山	一模一样	籍见门著

大海捞针	大海捞针	大捞海针	大官政针	半途而废	官捞海政
于事无补	于事无补	于无事补	于练着补	蠢蠢欲动	练无事着
物理学家	物理学家	物学理家	物焦心家	大发雷霆	焦学理心
不合时宜	不合时宜	不时合宜	不幼期宜	夷为平地	幼时合期
视而不见	视而不见	视不而见	视融出见	所作所为	融不而出
拭目以待	拭目以待	拭以目待	拭收载待	一触即发	收以目载
见不得人	见不得人	见得不人	见画掉人	土生土长	画得不掉
中产阶级	中产阶级	中阶产级	中冲干级	司法部长	冲阶产干
受宠若惊	受宠若惊	受若宠惊	受仰着惊	高尔夫球	仰若宠着
年复一年	年复一年	年一复年	年饭粮年	意想不到	饭一复粮
难以置信	难以置信	难置以信	难东庙信	人寿保险	东置以庙
一窍不通	一窍不通	一不窍通	一稍时通	担惊受怕	稍不窍时
史无前例	史无前例	史前无例	史肢下例	一般来说	
一事无成	一事无成	一无事成	一细柔成	隐姓埋名	
电话会议	电话会议	电会话议	电摸开议	谢天谢地	
并肩作战	并肩作战	并作肩战	并锯工战	另一方面	
到此为止	到此为止	到为此止	到消降止	闭路电视	
坐以待毙	坐以待毙	坐待以毙	坐此住毙	无拘无束	
指手画脚	指手画脚	指画手脚	指丧权脚	一厢情愿	
辛辛苦苦	辛辛苦苦	辛苦辛苦	辛善端苦	罪魁祸首	
以防万一	以防万一	以万防一	以解军一	第三世界	
起死回生	起死回生	起回死生	起长父生	彻头彻尾	
活蹦乱跳	活蹦乱跳	活乱蹦跳	活婚宅跳	得寸进尺	
无精打采	无精打采	无打精采	无牵于采	提心吊胆	
相提并论	相提并论	相并提论	相外核论	以牙还牙	
容光焕发	容光焕发	容焕光发	容备防发	从天而降	
众所周知	众所周知	众周所知	众跌退知	赴汤蹈火	
蒙在鼓里	蒙在鼓里	蒙鼓在里	蒙口记里	一臂之力	
十字路口	十字路口	十路字口	十附卧口	习以为常	
自找麻烦	自找麻烦	自麻找烦	自茶局烦	不仅如此	
危在旦夕	危在旦夕	危旦在夕	危悲催夕	迄今为止	
逍遥法外	逍遥法外	逍法遥外	逍原轴外	自然而然	
不同寻常	不同寻常	不寻同常	不相视常	发号施令	
打草惊蛇	打草惊蛇	打惊草蛇	打球具蛇	不管怎样	
出乎意料	出乎意料	出意乎料	出盘出料	老老实实	
无线电话	无线电话	无电线话	无相效话	死里逃生	
惊慌失措	惊慌失措	惊失慌措	惊割心措	善解人意	
公共场所	公共场所	公场共所	公应手所	职业道德	
生物学家	生物学家	生学物家	生弑身家	四分之一	
大干一场	大干一场	大一干场	大实货场	说三道四	
出人头地	出人头地	出头人地	出落户地	千里迢迢	
无关紧要	无关紧要	无紧关要	无抵灭要	全心全意	
至关重要	至关重要	至重关要	至照效要	白马王子	
整装待发	整装待发	整待装发	整灯口发	轻而易举	
人际关系	人际关系	人关际系	人出服系	种族歧视	
名副其实	名副其实	名其副实	名病室实	一清二楚	
融为一体	融为一体	融一为体	融缘巧体	亚历山大	
重蹈覆辙	重蹈覆辙	重覆蹈辙	重失赃辙	前所未有	
开诚布公	开诚布公	开布诚公	开习法公	各种各样	
共产主义	共产主义	共主产义	共家兵义	莎士比亚	

不顾一切	不顾一切	不一顾切	不戒入切	无可奉告
百万富翁	百万富翁	百富万翁	百轻写翁	游手好闲
重操旧业	重操旧业	重旧操业	重假于业	例行公事
出类拔萃	出类拔萃	出拔类萃	出受涨萃	为所欲为
绳之以法	绳之以法	绳以之法	绳水态法	天主教徒
毫不留情	毫不留情	毫留不情	毫理石情	孤注一掷
一见钟情	一见钟情	一钟见情	一国梁情	自暴自弃
自作聪明	自作聪明	自聪作明	自用军明	脱口而出
自由主义	自由主义	自主由义	自自渍义	身无分文
引人注目	引人注目	引注人目	引名物目	无与伦比
平安无事	平安无事	平无安事	平阅礼事	与此同时
不知所措	不知所措	不所知措	不法教措	扪心自问
无济于事	无济于事	无于济事	无实场事	循规蹈矩
华而不实	华而不实	华不而实	华抗党实	小道消息
改过自新	改过自新	改自过新	改亏尽新	飘飘欲仙
迫不及待	迫不及待	迫及不待	迫世境待	动手动脚
毋庸置疑	毋庸置疑	毋置庸疑	毋顺说疑	从那之后
夜以继日	夜以继日	夜继以日	夜退乡日	言归正传
特种部队	特种部队	特部种队	特亏事队	鸡毛蒜皮
奥林匹克	奥林匹克	奥匹林克	奥惧于克	有朝一日
随心所欲	随心所欲	随所心欲	随多题欲	实实在在
不可收拾	不可收拾	不收可拾	不应讨拾	从头到尾
化学反应	化学反应	化反学应	化年表应	有生之年
若无其事	若无其事	若其无事	若折销事	一败涂地
不过如此	不过如此	不如过此	不上骗此	澳大利亚
无名小卒	无名小卒	无小名卒	无对板卒	食物中毒
训练有素	训练有素	训有练素	训流用素	雄心壮志
置之不理	置之不理	置不之理	置寒灾理	进进出出
与众不同	与众不同	与不众同	与石牢同	心平气和
大惊小怪	大惊小怪	大小惊怪	大盗案怪	感情用事
一席之地	一席之地	一之席地	一促短地	惨不忍睹
无稽之谈	无稽之谈	无之稽谈	无水笼谈	臭名昭着
非同寻常	非同寻常	非寻同常	非遇合常	卷土重来
正当防卫	正当防卫	正防当卫	正叮附卫	巡回演出
哺乳动物	哺乳动物	哺动乳物	哺精实物	五角大楼
世界大战	世界大战	世大界战	世心眉战	单枪匹马
洗耳恭听	洗耳恭听	洗恭耳听	洗测象听	自欺欺人
一无所有	一无所有	一所无有	一牵上有	逃之夭夭
无家可归	无家可归	无可家归	无奋命归	简而言之
孤身一人	孤身一人	孤一身人	孤纳下人	隐形眼镜
蛛丝马迹	蛛丝马迹	蛛马丝迹	蛛调备迹	死路一条
脱颖而出	脱颖而出	脱而颖出	脱存养出	爱因斯坦
梦想成真	梦想成真	梦成想真	梦接议真	想方设法
安然无恙	安然无恙	安无然恙	安作端恙	基督教徒
防弹背心	防弹背心	防背弹心	防上战心	不择手段
后会有期	后会有期	后有会期	后军灾期	有限公司
梦寐以求	梦寐以求	梦以寐求	梦怠步求	当务之急
本职工作	本职工作	本工职作	本出落作	大喊大叫
完好无损	完好无损	完无好损	完转途损	婆婆妈妈
严阵以待	严阵以待	严以阵待	严枪标待	精疲力尽

不可思议	不可思议	不思可议	不白挨议	长话短说
守口如瓶	守口如瓶	守如口瓶	守授兵瓶	翻天覆地
尽力而为	尽力而为	尽而力为	尽求智为	水落石出
轻举妄动	轻举妄动	轻妄举动	轻调台动	似曾相识

Appendix B: Word Stimuli used in Chapter 3

Word Stimuli used in Experiment 3.1, 3.2 and 3.4

These stimuli served as word targets in Experiment 1. Eighty-nine of them served as word targets in Experiment 3.2 as we added one new target “出乎意料” and its syllabically related prime “廖议忽初”. Two hundred thirty-nine of the BR\BU primes and their word targets were used in the same trials in Experiment 3.4. One new target “舍己为人” and its backward prime “人为己舍” were added in Experiment 3.4.

SR means syllabically related backward prime, SU means syllabically unrelated backward prime, BR means backward related prime, and BU means backward unrelated prime.

Target	SR\SU prime	BR\BUprime	Target	SR\SU prime	BR\BUprime
有所不同	佟布琐友	同不所有	旗开得胜	剩德揩琪	胜得开旗
出人意料	瞭义仁初	料意人出	弃旧图新	心途救气	新图旧弃
有线电视	事店现友	视电线有	千里迢迢	条条李签	迢迢里千
精彩绝伦	囵决踩京	伦绝彩精	千人所指	趾索仁签	指所人千
竭尽全力	利权进洁	力全尽竭	穷凶极恶	饿集兄琼	恶极凶穷
不切实际	寄时窃部	际实切不	穷极无聊	辽吴吉琼	聊无极穷
身不由己	脊犹布申	己由不身	事必躬亲	侵宫碧式	亲躬必事
心不在焉	淹再步欣	焉在不心	殊途同归	规佟图书	归同途殊
直升飞机	击非生侄	机飞升直	束手就擒	琴旧守述	擒就手束
前功尽弃	气劲宫钱	弃尽功前	沉鱼落雁	艳洛于臣	雁落鱼沉
下定决心	新绝订夏	心决定下	天经地义	意第京添	义地经天
不可理喻	玉锂渴部	喻理可不	同归于尽	进鱼规佟	尽于归同
情不自禁	巾字布擎	禁自不情	同流合污	屋河刘佟	污合流同
辩护律师	诗绿互卞	师律护辩	痛不欲生	升玉布恸	生欲不痛
高速公路	鹿攻素羔	路公速高	望梅止渴	岢纸煤妄	渴止梅望
恐怖主义	意煮步孔	义主怖恐	欣欣向荣	容项新新	荣向欣欣
袖手旁观	关庞首秀	观旁手袖	夜深人静	径仁申业	静人深夜
自掘坟墓	目焚决字	墓坟掘自	优哉游哉	灾由灾攸	哉游哉优
好不容易	意绒布郝	易容不好	有备无患	焕吴被友	患无备有
感激不尽	近步机敢	尽不激感	有气无力	利吴弃友	力无气有
犹豫不决	绝布域邮	决不豫犹	原形毕露	鹿必邢圆	露毕形原
不久以后	厚蚁九步	后以久不	知难而进	浸儿男织	进而难知
物理学家	加穴李误	家学理物	中庸之道	稻织雍钟	道之庸中
拭目以待	岱已暮士	待以目拭	自不量力	利晾布字	力量不自
并肩作战	站做间病	战作肩并	独树一帜	治伊束毒	帜一树独
坐以待毙	币带蚁坐	毙待以坐	若有所失	师索友弱	失所有若
众所周知	织舟索仲	知周所众	跃跃欲试	仕玉悦悦	试欲跃跃

危在旦夕	西惮再薇	夕旦在危	木已成舟	州承以目	舟成已木
怅然若失	师弱呐唱	失若然怅	胸无点墨	沫典吴兄	墨点无胸
惊慌失措	挫诗荒茎	措失慌惊	杀身成仁	人承申纱	仁成身杀
生物学家	痂穴勿升	家学物生	独具匠心	辛酱距毒	心匠具独
共产主义	议煮阐贡	义主产共	坐享其成	承旗想做	成其享坐
毫不留情	擎刘布蚝	情留不毫	语惊四座	做寺精羽	座四惊语
自作聪明	鸣匆做字	明聪作自	手足无措	锉吴族首	措无足手
自由主义	异煮犹字	义主由自	瞻前顾后	厚固钱沾	后顾前瞻
引人注目	沐贮仁饮	目注人引	心余力绌	触利于新	绌力余心
不知所措	锉唢织布	措所知不	独木难支	芝男目毒	支难木独
随心所欲	玉锁欣绥	欲所心随	痴心妄想	响旺辛吃	想妄心痴
置之不理	礼步汁志	理不之置	坐井观天	添官景做	天观井坐
与众不同	彤布仲羽	同不众与	心急如焚	坟儒吉新	焚如急心
哺乳动物	务冻汝补	物动乳哺	故作姿态	泰孜坐顾	态姿作故
脱颖而出	初儿影拖	出而颖脱	殚精竭虑	绿杰京耽	虑竭精殚
梦寐以求	囚已媚孟	求以寐梦	摩肩接踵	肿阶坚馍	踵接肩摩
严阵以待	代已镇妍	待以阵严	自强不息	西布墙字	息不强自
不可思议	忆司渴布	议思可不	廉洁奉公	攻凤杰怜	公奉洁廉
混为一谈	坛伊违诨	谈一为混	竭泽而渔	于儿则劫	渔而泽竭
轻举妄动	冻忘矩青	动妄举轻	事出有因	音友初世	因有出事
焕然一新	芯医呐患	新一然焕	阳奉阴违	帷因凤洋	违阴奉阳
一干二净	境贰甘咿	净二干一	风驰电掣	彻玷迟锋	掣电驰风
宇宙飞船	遄非皱羽	船飞宙宇	萎靡不振	镇布迷伟	振不靡萎
诺贝尔奖	讲耳备懦	奖尔贝诺	首屈一指	纸咿驱手	指一屈首
岌岌可危	威渴吉吉	危可岌岌	持之以恒	衡乙织迟	恒以之持
应有尽有	酉近酉英	有尽有应	刺骨悬梁	粮玄股次	梁悬骨刺
时时刻刻	刻克时实	刻刻时时	忐忑不安	氨布特坦	安不忑忐
一动不动	冻布冻咿	动不动一	势均力敌	笛吏军室	敌力均势
与世隔绝	决骼事语	绝隔世与	众矢之的	弟织始仲	的之矢众
如愿以偿	尝已院儒	偿以愿如	浅尝辄止	纸哲常谴	止辄尝浅
循规蹈矩	举导归旬	矩蹈规循	匠心独运	孕毒辛酱	运独心匠
流言蜚语	雨非岩刘	语蜚言流	异曲同工	宫佟取译	工同曲异
玩忽职守	手值呼丸	守职忽玩	瓜熟蒂落	骡帝赎刮	落蒂熟瓜
一氧化碳	探话养咿	碳化氧一	十恶不赦	射布饿实	赦不恶十
分道扬镳	标阳到氛	镳扬道分	自不量力	利晾布字	力量不自
奄奄一息	西咿演演	息一奄奄	玉石俱焚	坟剧时芋	焚俱石玉
深信不疑	移布衅身	疑不信深	画饼充饥	击憧柄桦	饥充饼画
勇往直前	钱职网永	前直往勇	心悦诚服	符呈月新	服诚悦心
按部就班	搬旧布岸	班就部按	全军覆没	墨富君权	没覆军全
措手不及	即布首挫	及不手措	平步青云	匀轻布凭	云青步平
支离破碎	岁珀梨汁	碎破离支	挥霍无度	杜吴货恢	度无霍挥
装腔作势	事做枪妆	势作腔装	未雨绸缪	眸愁羽谓	缪绸雨未
闭路电视	室店鹿币	视电路闭	对症下药	曜夏郑兑	药下症对
不可开交	娇揩渴布	交开可不	名垂青史	矢轻搥明	史青垂名
为时已晚	碗乙实维	晚已时为	暴露无遗	怡吴鹿豹	遗无露暴
小心谨慎	肾谨新晓	慎谨心小	恪尽职守	手直进刻	守职尽恪
心甘情愿	院晴甘新	愿情甘心	悲天悯人	仁敏添杯	人悯天悲
振奋人心	新仁份震	心人奋振	惴惴不安	谙布坠坠	安不惴惴
一帆风顺	舜封翻咿	顺风帆一	意犹未尽	进位邮议	尽未犹意
漠不关心	新官布末	心关不漠	感人至深	申帜仁赶	深至人感

井井有条	迢友景景	条有井井	排除万难	男挽厨牌	难万除排
尽心尽力	利禁新近	力尽心尽	明文规定	订归闻名	定规文明
取而代之	汁带儿龋	之代而取	有求必应	硬币囚友	应必求有
自生自灭	蔑渍升字	灭自生自	杳无音信	衅阴吴咬	信音无杳
退伍军人	仁君舞蜕	人军伍退	残羹剩饭	范圣庚蚕	饭剩羹残
适可而止	止儿渴室	止而可适	洁身自好	浩字申杰	好自身洁
一成不变	遍布呈咿	变不成一	深不可测	策渴布身	测可不深
下不为例	力维布夏	例为不下	灵丹妙药	燿庙耽铃	药妙丹灵
不可告人	仁禞渴布	人告可不	登峰造极	吉皂枫灯	极造峰登
主治医生	升一智煮	生医治主	百依百顺	舜摆伊摆	顺百依百
文艺复兴	星负意闻	兴复艺文	百无聊赖	徕辽吴摆	赖聊无百
自由自在	再渍游字	在自由自	积极向上	尚像吉机	上向极积
不速之客	课织素布	客之速不	简明扼要	药饿名剪	要扼明简
唇齿相依	咿乡耻纯	依相齿唇	箭在弦上	尚贤再剑	上弦在箭
侃侃而谈	谭儿坎坎	谈而侃侃	红极一时	实医级洪	时一极红
量入为出	初违缛晾	出为入量	股份公司	斯宫奋古	司公份股
呕心沥血	穴立辛偶	血沥心呕	自学成才	裁承穴渍	才成学自
扑朔迷离	梨弥烁噗	离迷朔扑	芸芸众生	声仲匀匀	生众芸芸
骑虎难下	夏男浒旗	下难虎骑	虚无主义	译煮吴须	义主无虚
轻而易举	矩义儿青	举易而轻	谈笑风生	升丰效谭	生风笑谈
守株待兔	吐带猪首	兔待株守	财政部长	掌布郑裁	长部政财
浩浩荡荡	档档耗耗	荡荡浩浩	严丝合缝	奉河司妍	缝合丝严
畏首畏尾	诿未守未	尾畏首畏	临阵磨枪	腔馍朕邻	枪磨阵临
人云亦云	匀议匀仁	云亦云人	举手投足	族头首矩	足投手举
百读不厌	谚布独摆	厌不读百	举步维艰	坚帏布矩	艰维步举
风声鹤唳	栗赫升锋	唳鹤声风	久负盛名	明剩付九	名盛负久
福星高照	诏羔惺符	照高星福	乔迁之喜	徙汁签樵	喜之迁乔
俯拾即是	世籍实斧	是即拾俯	亭亭玉立	吏芋廷廷	立玉亭亭
固执己见	件挤侄顾	见己执固	人迹罕至	志喊计仁	至罕迹人
管中窥豹	报亏终筦	豹窥中管	众志成城	丞承帜仲	城成志众
狐假虎威	危浒甲壶	威虎假狐	优胜劣汰	泰烈圣悠	汰劣胜优
画蛇添足	族天舌桦	足添蛇画	伶牙俐齿	耻吏涯灵	齿俐牙伶
疾恶如仇	绸儒饿极	仇如恶疾	勤勤恳恳	肯肯秦秦	恳恳勤勤
焦头烂额	鹅滥投胶	额烂头焦	化学元素	肃园穴桦	素元学化
劳逸结合	河杰议牢	合结逸劳	半身不遂	随布深办	遂不身半
毛遂自荐	剑渍岁矛	荐自遂毛	变化无常	偿吴桦遍	常无化变
美中不足	族布钟每	足不中美	只身一人	仁伊深支	人一身只
名列前茅	毛钱猎明	茅前列名	各取所需	虚锁龋隔	需所取各
明察秋毫	蚝丘茶名	毫秋察明	合成纤维	违先城河	维纤成合
磨杵成针	贞承楚膜	针成杵磨	名留青史	始轻刘明	史青留名
破釜沉舟	州臣府珀	舟沉釜破	哭笑不得	德布效枯	得不笑哭
七上八下	夏芭尚漆	下八上七	因人而异	亿儿仁音	异而人因
堂而皇之	支黄儿谈	之皇而堂	垂涎欲滴	低玉闲槌	滴欲涎垂

Word Stimuli used in Experiment 3.3

TL means transposed prime, UN means unrelated prime, SM means single-morpheme, and TM means two-morpheme. The stimuli was the same as that used in Gu et al. (2015).

SM word targets	TL	UN	TM word targets	TL	UN
萧瑟	瑟萧	粱崭	哀婉	婉哀	渍耍
吝啬	啬吝	菠汞	谦逊	逊谦	虐愣
恢弘	弘恢	叨胀	俊逸	逸俊	庵旺
枷锁	锁枷	膜涎	谕旨	旨谕	尘帷
荆棘	棘荆	腌昭	嘲讽	讽嘲	灿橡
乾坤	坤乾	驹赎	酷暑	暑酷	凿殿
痉挛	挛痉	恙氨	腹泻	泻腹	饲魂
斟酌	酌斟	捍靶	捆绑	绑捆	柳豹
魁梧	梧魁	衅畸	陡峭	峭陡	诽栋
侥幸	幸侥	爸肽	崇敬	敬崇	秘婆
纰漏	漏纰	填妤	秧苗	苗秧	昂朕
跌宕	宕跌	苷堪	懈怠	怠懈	峦撼
锦绣	绣锦	株瑞	稀疏	疏稀	矮腔
莽撞	撞莽	踏紊	酣畅	畅酣	押颌
迂腐	腐迂	雇氖	俏丽	丽俏	垂浇
滑稽	稽滑	幢措	幼稚	稚幼	猿讼
荒诞	诞荒	狱罢	烦躁	躁烦	嚷捕
陀螺	螺陀	疆妒	褶皱	皱褶	谊穆
寒暄	暄寒	溥童	逃窜	窜逃	氮症
妖冶	冶妖	杠灶	幽僻	僻幽	蝗垒
翩跹	跹翩	滟墩	钦慕	慕钦	裹鸦
凄怆	怆凄	虬胳	暮霭	霭暮	羸暨
彪炳	炳彪	轲痒	悖逆	逆悖	氢唠
乖戾	戾乖	庖卓	愚钝	钝愚	籽窝
飒爽	爽飒	盒眈	贤惠	惠贤	笼茎
阑珊	珊阑	诬痣	柔媚	媚柔	猬炭
拖沓	沓拖	肴肿	庸碌	碌庸	锤崖
颠沛	沛颠	伺赚	嫌弃	弃嫌	寺摊
芦笙	笙芦	冕秃	陶俑	俑陶	枸牺
绚烂	烂绚	叔骇	儒雅	雅儒	腊憾
鄙夷	夷鄙	贞滔	晦涩	涩晦	挫烽
斑驳	驳斑	诊傲	鼎沸	沸鼎	肪硫
泼辣	辣泼	辐弦	聪颖	颖聪	韵踪
跋扈	扈跋	痊皖	狡诈	诈狡	抚祆
偏袒	袒偏	涣韩	震慑	慑震	缤餐
惨淡	淡惨	峰锅	壮阔	阔壮	殖妹
凌驾	驾凌	胶铅	撕毁	毁撕	煤瞒
摇曳	曳摇	戌骶	偷窃	窃偷	垫炼

糟蹋	蹋糟	孺膨	羞辱	辱羞	赁臭
戈壁	壁戈	燃爪	捷径	径捷	刷滋
牢骚	骚牢	裤昏	怨恨	恨怨	昨拳
殷勤	勤殷	辞俺	嘉宾	宾嘉	贪誓
敷衍	衍敷	垮鞍	冤枉	枉冤	呱帘
抑郁	郁抑	刹沫	狭隘	隘狭	婿拱
奢侈	侈奢	拇萎	诚恳	恳诚	聋拨
晶莹	莹晶	冥筒	晴朗	朗晴	浙喘
昂扬	扬昂	阵贪	哀伤	伤哀	吃垫
烂漫	漫烂	摘胎	浑厚	厚浑	盾牲
纠葛	葛纠	絮伐	焦灼	灼焦	坞赏
盘缠	缠盘	辐夏	浆糊	糊浆	撤衰
杜鹃	鹃杜	揩冶	池塘	塘池	溢仰
喷薄	薄喷	墨腔	攀爬	爬攀	贩覆
笼络	络笼	钢萄	拆毁	毁拆	磁卧
琢磨	磨琢	趣蛛	诈骗	骗诈	喊抖
搭讪	讪搭	仞缘	昏厥	厥昏	遐贯
横亘	亘横	臼酸	雄踞	踞雄	鲤湾
狼藉	藉狼	襄颂	羞怯	怯羞	耶晓
颓丧	丧颓	麦跷	琐屑	屑琐	逆婶
袅娜	娜袅	俐茸	娇憨	憨娇	霄哑
恫吓	吓恫	圳盹	羁押	押羁	诱簧

Kanji Word Stimuli used in Experiment 3.5

Rep means repetition prime, TC means transposed character prime, Hira means Hiragana TC prime, and Sub means substituted character prime.

Rep Prime	TC Prime	Hira Prime	Sub Prime	Target
相互依存	相依互存	相いご存	相失皮存	相互依存
百科事典	百事科典	百じか典	百走琢典	百科事典
一部負担	一負部担	一ふぶ担	一南冠担	一部負担
国語辞典	国辞語典	国じご典	国総球典	国語辞典
養護施設	養施護設	養しご設	養末暖設	養護施設
進路指導	進指路導	進しろ導	進円道導	進路指導
控訴期間	控期訴間	控きそ間	控詔逆間	控訴期間
奈良時代	奈時良代	奈じら代	奈釈狗代	奈良時代
文化遺産	文遺化産	文いか産	文侃善産	文化遺産
石油化学	石化油学	石かゆ学	石悠訴学	石油化学
地下都市	地都下市	地とか市	投穫愁場	地下都市
外貨預金	外預貨金	外よか金	外席宝金	外貨預金
母子家庭	母家子庭	母かし庭	母舶期庭	母子家庭
基礎医学	基医礎学	基いそ学	基傾膨学	基礎医学
英和辞典	英辞和典	英じわ典	英滴傾典	英和辞典

電気化学	電化気学	電かき学	電欺京学	電気化学
人事異動	人異事動	人いじ動	人九捜動	人事異動
野良仕事	野仕良事	野しら事	野転知事	野良仕事
二次試験	二試次験	二しじ験	二感棄験	二次試験
作為義務	作義為務	作ぎい務	作凍縮務	作為義務
名誉棄損	名棄誉損	名きょ損	名詔整損	名誉棄損
認知科学	認科知学	認かち学	認候鹿学	認知科学
天気予報	天予気報	天よき報	天比通報	天気予報
単位未満	単未位満	単みい満	単奈字満	単位未満
物価手当	物手価当	物てか当	物力浄当	物価手当
当座預金	当預座金	当よざ金	当略攘金	当座預金
薬理作用	薬作理用	薬さり用	地暖級川	薬理作用
歴史科学	歴科史学	歴かし学	歴侃爆学	歴史科学
初期微動	初微期動	初びき動	初之衣動	初期微動
相互作用	相作互用	相さご用	相労照用	相互作用
模擬試験	模試擬験	模しぎ験	模貴掻験	模擬試験
弁護士法	弁士護法	弁しご法	弁字始法	弁護士法
注意義務	注義意務	注ぎい務	注斜建務	注意義務
軍事基地	軍基事地	軍きじ地	軍想車地	軍事基地
無我夢中	無夢我中	無むが中	無巳記中	無我夢中
消費市場	消市費場	消しひ場	消書喧場	消費市場
弁護士会	弁士護会	弁しご会	弁願再会	弁護士会
政治意識	政意治識	政いじ識	政奇超識	政治意識
刑事訴追	刑訴事追	刑そじ追	刑舞岡追	刑事訴追
基礎知識	基知礎識	基ちそ識	基泰覚識	基礎知識
臨時試験	臨試時験	臨しじ験	臨織道験	臨時試験
生徒手帳	生手徒帳	生てと帳	生識事帳	生徒手帳
都市気候	都気市候	都きし候	都需竜候	都市気候
前後左右	前左後右	前さご右	前憶排右	前後左右
公訴時効	公時訴効	公じそ効	公仮探効	公訴時効
交互作用	交作互用	交さご用	交賊赴用	交互作用
温故知新	温知故新	温ちこ新	温淀街新	温故知新
危機意識	危意機識	危いき識	危響薬識	危機意識
道路施設	道施路設	道しろ設	道解湿設	道路施設
大気汚染	大汚気染	大おき染	大租局染	大気汚染
消費支出	消支費出	消しひ出	消旋蛇出	消費支出
定期預金	定預期金	定よき金	福農酬設	定期預金
自己破産	自破己産	自はこ産	自礼灯産	自己破産
自己負担	自負己担	自ふこ担	自充裁担	自己負担
飽和市場	飽市和場	飽しわ場	飽声様場	飽和市場
自己意識	自意己識	自いこ識	自衡淵識	自己意識
証拠保全	証保拠全	証ほこ全	証開為全	証拠保全
原始時代	原時始代	原じし代	原園史代	原始時代
巡査部長	巡部査長	巡ぶさ長	巡近炭長	巡査部長
皮下脂肪	皮脂下肪	皮しか肪	皮貝貿肪	皮下脂肪
過疎地帯	過地疎帯	過ちそ帯	過季秩帯	過疎地帯
中期予報	中予期報	中よき報	中井弱報	中期予報
白紙委任	白委紙任	白いし任	白怪心任	白紙委任
消化不良	消不化良	消ふか良	消凍長良	消化不良
漢和辞典	漢辞和典	漢じわ典	漢裁門典	漢和辞典

有機化学	有化機学	有かき学	有晶羅学	有機化学
言語技術	言技語術	言ぎご術	言坪退術	言語技術
事務次官	事次務官	事じむ官	事惑陸官	事務次官
支持価格	支価持格	支かじ格	支事自格	支持価格
調査不能	調不査能	調ふさ能	調罪指能	調査不能
一次試験	一試次験	一しじ験	一枯費験	一次試験
元素記号	元記素号	元きそ号	元精召号	元素記号
不可思議	不思可議	不しか議	不献鏤議	不可思議
決議事項	決事議項	決じぎ項	決究活項	決議事項
筆記試験	筆試記験	筆しき験	筆鈴誠験	筆記試験
賞味期間	賞期味間	賞きみ間	賞隆士間	賞味期間
低利資金	低資利金	低しり金	低会講金	低利資金
長期保険	長保期険	長ほき険	長録赤険	長期保険
短期保護	短保期護	短ほき護	短移畜護	短期保護
予備知識	予知備識	予ちび識	予独荷識	予備知識

Katakana Word Stimuli used in Experiment 3.5

Rep Prime	TC Prime	Hira Prime	Sub Prime	Target
カンバス	カバンス	カばんス	カブドス	カンバス
トラスト	トスラト	トすらト	トハムト	トラスト
ニンニク	ニニンク	ニにんク	ニバカク	ニンニク
オカルト	オルカト	オるかト	オヅウト	オカルト
プリンス	プンリス	プんりス	プケノス	プリンス
マガジン	マジガン	マじがン	マヂチン	マガジン
クラウン	クウラン	クうらン	クサフン	クラウン
カナリア	カリナア	カりなア	カギコア	カナリア
スライド	スイラド	スいらド	スタヂド	スライド
クラフト	クフラト	クふらト	クユゴト	クラフト
ダイヤル	ダヤイル	ダやいル	ダデカル	ダイヤル
クレソン	クソレン	クそれン	クヴビン	クレソン
ノンプロ	ノプンロ	ノぷんロ	ノギヌロ	ノンプロ
ミニマム	ミマニム	ミまにム	ミプイム	ミニマム
コバルト	コルバト	コるばト	コデテト	コバルト
ユニオン	ユオニン	ユおにン	ユムウン	ユニオン
セロハン	セハロン	セはろン	セグバン	セロハン
モルタル	モタルル	モたるル	モヌヤル	モルタル
プラズマ	プズラマ	プずらマ	プニヤマ	プラズマ
タンポポ	タポンポ	タぽんポ	タワロポ	タンポポ
アンテナ	アテンナ	アてんナ	アウヴナ	アンテナ
リタイア	リイタア	リいたア	リトカア	リタイア
ロザリオ	ロリザオ	ロりざオ	ロベドオ	ロザリオ
スクイズ	スイクズ	スいくズ	スソサズ	スクイズ
ナメクジ	ナクメジ	ナくめジ	ナマゾジ	ナメクジ
ルンペン	ルペンン	ルぺんン	ルオスン	ルンペン
フランク	フンラク	フんらク	フゼスク	フランク
ソビエト	ソエビト	ソえびト	ソヒクト	ソビエト
インテリ	イテンリ	イてんリ	イコルリ	インテリ
ヘリウム	ヘウリム	へうりム	ヘソベム	ヘリウム

ブルペン	ブペルン	ブぺるン	ブヤフン	ブルペン
ゴンドラ	ゴドンラ	ゴどんラ	ゴヂピラ	ゴンドラ
ロイヤル	ロヤイル	ロやいル	ロゼポル	ロイヤル
アメンボ	アンメボ	アんめボ	アパコボ	アメンボ
ハングル	ハグンル	ハぐんル	ハデゾル	ハングル
キラキラ	キキララ	キきらラ	キタリラ	キラキラ
リウマチ	リマウチ	リまうチ	リスグチ	リウマチ
エアバス	エバアス	エばあス	エヲワス	エアバス
トンカチ	トカンチ	トかんチ	トサペチ	トンカチ
ミニコミ	ミコニミ	ミこにミ	ミゴシミ	ミニコミ
ピクルス	ピルクス	ピるくス	ピラサス	ピクルス
オリオン	オオリン	オおりン	オヒギン	オリオン
ホステル	ホテスル	ホてすル	ホチギル	ホステル
アネモネ	アモネネ	アもねネ	アガユネ	アネモネ
ロマンス	ロンマス	ロんまス	ロヲピス	ロマンス
テフロン	テロフン	テろふン	テエペン	テフロン
バイキン	バキイン	バきいン	バヲタン	バイキン
テレホン	テホレン	テほれン	テボガン	テレホン
イレブン	イブレン	イぶれン	イテケン	イレブン
ギロチン	ギチロン	ギちろン	ギジバン	ギロチン
コサイン	コイサン	コいさン	コケヨン	コサイン
ドリブル	ドブリル	ドぶりル	ドコモル	ドリブル
ハモニカ	ハニモカ	ハにもカ	ハマケカ	ハモニカ
ケミカル	ケカミル	ケかみル	ケマホル	ケミカル
タフガイ	タガフイ	タがふイ	タチゴイ	タフガイ
タンメン	タメンン	タめんン	タビコン	タンメン
デザイン	デイザン	デいざン	デハゴン	デザイン
セミプロ	セプミロ	セぷみロ	セジドロ	セミプロ
フラスコ	フスラコ	フすらコ	フホウコ	フラスコ
パプリカ	パリプカ	パりぷカ	パゾガカ	パプリカ
ソナチネ	ソチナネ	ソちなネ	ソガポネ	ソナチネ
カリウム	カウリム	カうりム	カヒゲム	カリウム
コミカル	コカミル	コかみル	コハドル	コミカル
ボルシチ	ボシルチ	ボしるチ	ボヌヨチ	ボルシチ
クレヨン	クヨレン	クよれン	クピキン	クレヨン
トランス	トンラス	トんらス	トザシス	トランス
ステレオ	スレテオ	スれてオ	スホヨオ	ステレオ
ウインド	ウンイド	ウんいド	ウゼアド	ウインド
マラリア	マリラア	マりらア	マメヨア	マラリア
コウモリ	コモウリ	コもうリ	コヌポリ	コウモリ
シグナル	シナグル	シなぐル	シペバル	シグナル
ミリオン	ミオリン	ミおりン	ミヌノン	ミリオン
ウエイト	ウイエト	ウいえト	ウキボト	ウエイト
ピンポン	ピポンン	ピぽんン	ピテカン	ピンポン
テナント	テンナト	テんなト	テヲチト	テナント
シリアス	シアリス	シありス	シナノス	シリアス
セイウチ	セウイチ	セういチ	セペヨチ	セイウチ
グラビア	グビラア	グびらア	グタテア	グラビア
ガソリン	ガリソン	ガりそン	ガギネン	ガソリン
コンパス	コパンス	コぱんス	コイノス	コンパス

Appendix C: Word and Nonword Stimuli used in Chapter 4

All these below stimuli were used in Experiment 4.1 and 4.2.

Word target	TL Prime	SL prime	Nonword target	TL Prime	SL prime
PROVE	porve	pamve	POUGH	poguh	posih
DREAM	deram	dulam	GOUTH	gotuh	gosih
FRUIT	furit	fohit	JEIST	jesit	jecut
SMOKE	somke	sarke	DOISE	dosie	dozae
PLAIN	palin	pehin	LOUCH	locuh	loreh
SHOCK	sohck	salck	HEIZE	hezie	hesae
PROUD	porud	penud	BLORE	blroe	blgue
CHEAP	cehap	corap	LOAST	losat	locit
PLATE	palte	puhte	VOUGH	voguh	vojah
TREAT	terat	tolat	PLICE	plcie	plbee
CREAM	ceram	cowam	TOGUE	touge	toake
CHAIN	cahin	curin	BRILE	brlie	brfoe
JOINT	jonit	jolut	SPAIL	sapil	sotil
FAULT	falut	fagot	THEAD	tehad	tutad
GUILT	gulit	gudet	STOAL	sotal	siral
TOUGH	toguh	tonih	STEAN	setan	siran
GUIDE	gudie	gucae	PRAIL	paril	pehil
FAINT	fanit	famut	GRITE	girte	galte
COACH	cocah	cosuh	SHERE	sehre	sorre
MOUNT	monut	morit	SLAIR	salir	sorir
PAUSE	pasue	pacoe	BRONE	borne	bulne
WOUND	wonud	worad	CROVE	corve	cunve
GUEST	guset	gulat	DRUDE	durde	dinde
BEARD	berad	becud	GRUTE	gurte	gilte
SHORE	sohre	sacre	GUTCH	gucth	gurnh
SHADE	sahde	sirde	CHIRM	chrim	chlum
SHAME	sahme	sonme	SNART	snrat	snmit
SCORE	socre	sarre	CHULK	chluk	chtok
PRIZE	pirze	palze	GLIMB	glmib	glcub
BENCH	bnech	blach	PLOTH	pltoh	plnuh
BRAVE	barve	butve	GLUCK	glcuk	glmik
TRACE	tarce	tolce	GLUNK	glnuk	glgak
SNAKE	sanke	solke	CRIMB	crmib	crceb
STAKE	satke	sidke	RODGE	rogde	rorle
SCOPE	socpe	suspe	HETCH	hecth	hesdh
SLAVE	salve	sihve	FLIRK	flrik	flwok
TASTE	tatse	tadce	SLUNT	sulnt	sornt
FLESH	flseh	flrah	GLASH	galsh	gutsh
TRUCK	trcuk	trtok	FLUMP	fulmp	fermp
CLERK	clrek	clcuk	GLURP	gulrp	gabrp

DEPTH	detph	denlh	TRUSH	tursh	tilsh
FENCE	fecne	fesle	SPACK	sapck	sibck
TREND	trned	trvid	DRIRK	dirrk	dulrk
GROSS	grsos	grcas	SCIFF	sicff	sohff
SOLVE	sovle	sosre	PLUFF	pulff	porff
SMART	smrat	smlit	THILL	tihll	terll
FLASH	flsah	flrih	CHORT	cohrt	ciprt
STRIP	stirp	stacp	BLICK	bilck	borck
SKILL	sikll	sojll	GRAWN	grwan	grgen
SPLIT	slpit	srbit	PROCK	prcok	prmak
BLIND	bilnd	behnd	TURGE	tugre	tunle
CLOCK	colck	circk	SLAMP	slmap	slrep
SHIFT	sihft	sarft	TRANT	trnat	trsot
HENCE	hnece	hmoce	SHARF	shraf	shlef
SWING	siwng	sotng	BISER	biesr	biacr
GRANT	garnt	gilnt	LOVEN	loevn	loawn
SHELL	sehll	sibll	CRECK	crcek	crlak
STORM	sotrm	sulrm	TRONG	trnog	trmig
STIFF	sitff	serff	SNART	snrat	sngot
FIFTH	ffith	ftoth	BLILD	bllid	bltud
QUICK	qucik	qusek	DRAID	darid	delid
BEACH	becah	benuh	PRAIN	parin	polin
NOISE	nosie	nogue	TREAK	terak	tulak
BOUND	bonud	bosad	BLIEF	bilef	bahef
LAUGH	laguh	lasih	BRUNE	burne	bolne
COAST	cosat	cocet	CHAVE	cahve	curve
RAISE	rasie	rague	SLUTE	sulte	sarte
TEACH	tecah	tenuh	BRUEL	burel	balel
ROUGH	roguh	rotah	DRAIL	daril	dolil
POUND	ponud	pomid	FLEAK	felak	forak
ROUTE	rotue	ronie	GLAIN	galin	gepin
PAINT	panit	palut	FLEAD	felad	fuhad
CLOUD	colud	carud	PROKE	prkoe	prjue
SWEAT	sewat	sipat	PLORE	plroe	plsae
GRAIN	garin	gehin	KNOUT	knuot	knaet
TRAIL	taril	tupil	GLAST	glsat	glnit
SPITE	sipte	salte	PLEND	plned	plmud
CRIME	cirme	cohme	GLIND	glnid	glcud
SPARE	sapre	sirre	PLUNT	plnut	plcit
BLAME	balme	bihme	GOTCH	gocth	gonlh
CHOSE	cohse	carse	FRICK	frcik	frtek
GRAVE	garve	gohve	TRINK	trnik	trwok
THEME	tehme	tanme	BRITH	brtih	brceh
GRACE	garce	gohce	PROWN	prwon	prlin
YIELD	yiled	yigud	GRIVE	girve	gonve

SAUCE	sacue	sasoe	DRINE	dirne	dacne
VAGUE	vauge	vaije	SORGE	sroge	slage
TRUST	trsut	trcot	SCADE	sacde	sunde
THICK	thcik	thzek	DRAZE	darze	dolze
CROSS	crsos	crles	SNAZE	sanze	sutze
WASTE	watse	wafce	TRAKE	tarke	totke
SMELL	smlel	smtil	STELL	setll	sarll
STUFF	stfuf	stsef	STORT	sotrt	surrt
BIRTH	bitrh	bicdh	DIGHT	dgiht	druht
GUESS	guses	gutas	TRULL	turll	tahll
MATCH	macth	masdh	CRUNK	curnk	calnk

Appendix D: Ethical Approval

Western
Research

Date: 23 January 2018

To: Prof. Stephen Lupker

Project ID: 108835

Study Title: An examination of lexical processing in Chinese-English bilinguals

Application Type: Continuing Ethics Review (CER) Form

Review Type: Delegated

Date Approval Issued: 23/Jan/2018

REB Approval Expiry Date: 08/Feb/2019

Dear Prof. Stephen Lupker,

The Western University Research Ethics Board has reviewed the application. This study, including all currently approved documents, has been re-approved until the expiry date noted above.

REB members involved in the research project do not participate in the review, discussion or decision.

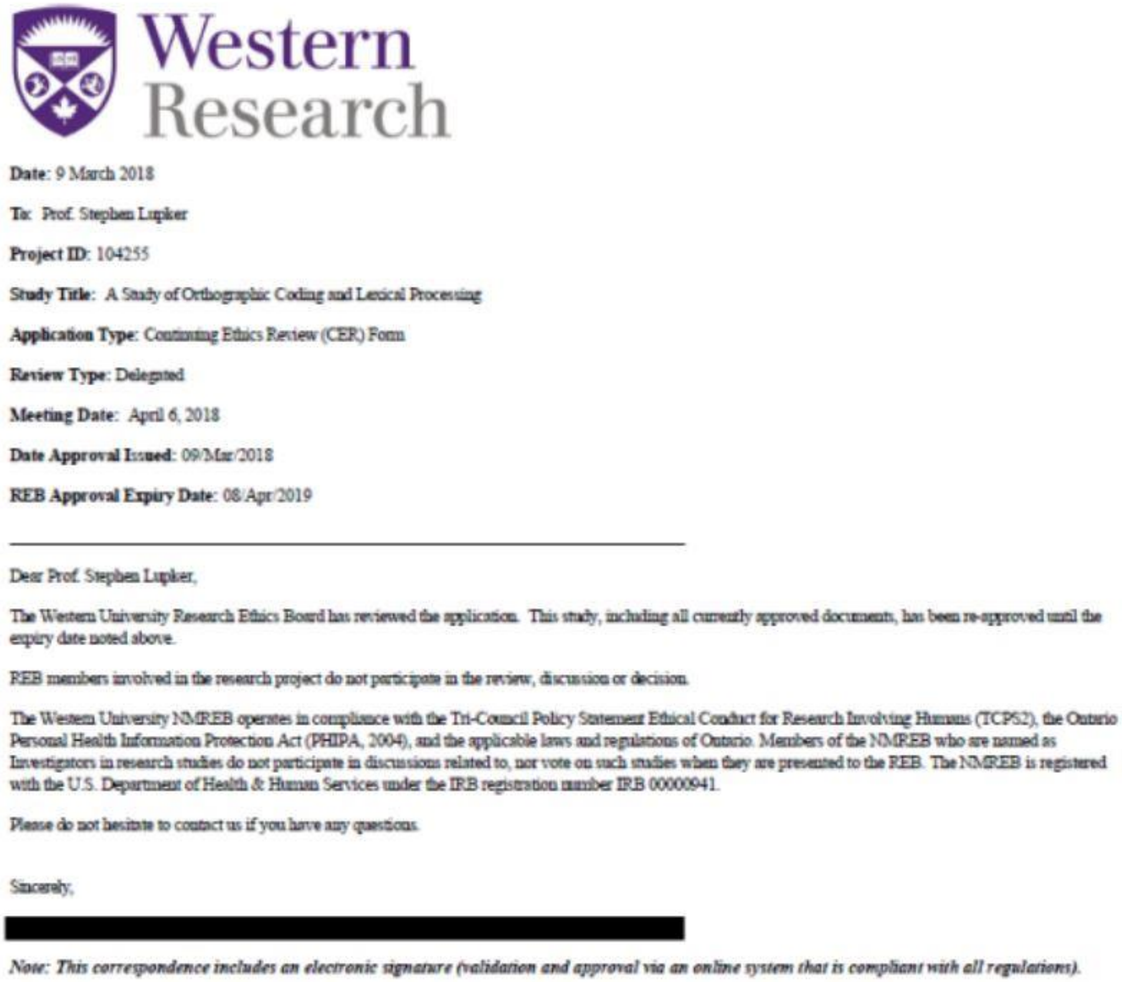
The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario. Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB. The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

Please do not hesitate to contact us if you have any questions.

Sincerely,

[redacted]

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).



Western Research

Date: 9 March 2018

To: Prof. Stephen Lupker

Project ID: 104255

Study Title: A Study of Orthographic Coding and Lexical Processing

Application Type: Continuing Ethics Review (CER) Form

Review Type: Delegated

Meeting Date: April 6, 2018

Date Approval Issued: 09/Mar/2018

REB Approval Expiry Date: 08/Apr/2019

Dear Prof. Stephen Lupker,

The Western University Research Ethics Board has reviewed the application. This study, including all currently approved documents, has been re-approved until the expiry date noted above.

REB members involved in the research project do not participate in the review, discussion or decision.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario. Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB. The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

Please do not hesitate to contact us if you have any questions.

Sincerely,

[redacted]

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).

Appendix E: Curriculum Vitae

Huilan Yang

PERSONAL INFORMATION

Department of Psychology

Ph.D

University of Western Ontario

London, Ontario CANADA

EDUCATION INFORMATION

PhD in Psychology **2016-20**
Western University, ON, Canada

ME in Psychology **2013-16**
South China Normal University, GuangDong, China

BA with Honours in Psychology **2009-13**
Hunan University of Science and Technology, Hunan, China

RESEARCH EXPERIENCE

PhD Research **2016-2020**
Department of Cognitive Psychology, University of Western Ontario

- Conducted research in Dr. Stephen J. Lupker's Psycholinguistics lab
- Dissertation research explored whether the orthographic coding for English and Chinese readers is based on abstract letter identities
- Research also contrasted letter position coding flexibility in different languages (e.g., English, Chinese, Japanese, Spanish, and Arabic readers), in order to test the performance orthographic coding models across different languages
- Other research projects explored phonological priming effects in logographic languages (Chinese and Japanese); cultural embodied representations for power related words.
- Familiar with using Generalized Linear Mixed-effects models and Linear Mixed-effects models
- Familiar with easyNet (Adelman, Gubian & Davis, in preparation), a simulation program for predicting masked orthographic priming effects

Masters Research **2013-2016**

Department of Developmental Psychology, South China Normal University

- Conducted research in Dr. Xianyou He's language processing lab
- Research concerned the embodied representations of abstract concepts (e.g., power, time, etc.) in Chinese

Honours Research **2009-2013**

Department of Psychology, Hunan University of Science and Technology

- Conducted research under the supervision of Dr. Jingjun Chen and Ningning Zhan
- Research focused on teacher competence and professional development

RESEARCH INTERESTS

Subliminal/Masked Priming Effects; Character/letter and Word Identification; Word Recognition Models; Model comparison; Embodied Cognition

PUBLICATIONS

1. **Yang, H.**, Hino, Y., Yoshihara. M., Chen, J., Nakayama. M., Xue, J., & Lupker, S. J. (2020). The Origins of Backward Priming Effects in Logographic Scripts for Four-Character Words. *Journal of Memory and Language, 113*, 104107. https://doi.org/10.1016/j.jml.2020.104107
2. **Yang, H.,** Chen, J., Spinelli, G., & Lupker, S. J. (2019). The Impact of Text Orientation on Transposed Character Priming Effects in Four-Character Chinese Words. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. *45*(8), 1511–1526. https://doi: 10.1037/xlm0000655
3. **Yang, H.,** & Lupker, S. J. (2019). Does Letter Rotation Decrease Transposed Letter Priming Effects? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 45*(12), 2309–2318.
4. **Yang, H.**, & Lupker, S. J. (2019). A Re-examination of Consonant-Vowel Differences in TL Priming Effects with English Words. *The Canadian Journal of Experimental Psychology.* Advance online publication. https://doi.org/10.1037/cep0000195

5. **Yang, H.**, He, X., Zhao, X., & Zhang, W. (2015). Multiple Metaphorical Representations of Power: Evidence from Size and Color. *Acta Psychologica Sinica, 47*(7), 939–949. (In Chinese)
6. **Yang, H.**, Xie, Y., Zhao, X., Zhang, W., & He, X. (2015). The Effect of Event Duration on the Updating of Situation Model. *Journal of Psychological Science, 39*(2), 285–290. (In Chinese)
7. **Yang, H.,** Zhan, N., Chen, J., He, X. Elementary and Secondary Teachers' Competence and Professional Development：Mediating Role of Professional Identity. *Science of Social Psychology, 30*(1), 35-44. (In Chinese)
8. He, X., **Yang, H.**, Zhang, W., Zhao, X., & Xie, Y. (2015). Dynamic Updating Process of Readers' Temporal Situation Model: From Short-term Working Memory to Long-term Working Memory. *Acta Psychologica Sinica, 47*(10), 1235–1246. (In Chinese)
9. Zhao, X., He, X., Zhao, T., **Yang, H.**, Lin, X., & Zhang, W. (2014). The Updating of Situation Model: Further Evidence of Event Frame-Dependent Hypothesis. *Acta Psychologica Sinica, 46*(7), 901–911. (In Chinese)
10. He, X., Zhao, X., **Yang, H.**, Lai S., & Lin, X. (2013). The updating of temporal situation model: The Event Frame-Dependent Hypothesis. *Journal of South China Normal University,* (5), 112–117. (In Chinese)
11. Liu, M., Zhang, J., Hu, E., **Yang, H.**, Cheng, C., & Yao, S. (2019). Combined patterns of physical activity and screen-related sedentary behavior among Chinese adolescents and their correlations with depression, anxiety and self-injurious behaviors. *Psychology research and behavior management, 12,* 1041-1050. doi: 10.2147/PRBM.S220075

PUBLICATIONS IN PREPARATION

1. **Yang, H.,** Nakayama. M., & Lupker, S. J. (In preparation). Phonological Priming Effects with Logographic Languages in Masked Same-different Task.
2. **Yang, H.**, Jared, D., Perea, M., & Lupker, S. J. (In preparation). Letter Position Coding Flexibility in Bilinguals.

CONFERENCE POSTERS

1. **Yang, H.**, Reid, J. N., & Katz, A. N. (2019). Social power and approach behaviour in English vs. Mandarin speakers. Presented at the 60th Annual Meeting of the Psychonomic Society, Montreal, PQ. November 14th - 17th, 2019.
2. **Yang, H.**, Jared, D., Perea, M., & Lupker, S. J. (2019). Letter Position Coding Flexibility in Bilinguals. Presented at The 29th Annual Meeting of the CSBBCS, Waterloo, ON. June 7th - 9th, 2019.
3. **Yang, H.,** & Lupker, S. J. (2018). A Re-examination of Consonant-Vowel Differences in TL Priming Effects with English Words. Presented at the 59th Annual Meeting of the Psychonomic Society, New Orleans, LA. November 15th - 18th, 2018.
4. **Yang, H.,** Chen, J., & Lupker, S. J. (2017). Does Visuospatial Orientation Have An Influence on Transposed Character Effects? Presented at the 58th Annual Meeting of the Psychonomic Society, Vancouver, BC. November 9th - 12th, 2017.
5. **Yang, H.,** & He, X. (2014). Multiple Metaphorical Representations of Power: Evidence from Size and Color. Poster presented at the 17th Annual Meeting of the Chinese Psychological Society, Beijing, BJ. October 10th - 12th, 2014.

EMPLOYMENT HISTORY

1. Teaching Assistant for Psychology 1000 Course “Introduction to Psychology”, Western University, Fall 2018, Winter 2019
2. Lab instructor for Psychology 2820E Course “Research Methods and Statistical Analysis in Psychology”, Western University, Fall 2017, Winter 2018
3. Teaching Assistant for Psychology 1000 Course “Introduction to Psychology”, Western University, Fall 2016, Winter 2017

ACADEMIC HONORS

2018	Social Science Graduate Research Award, Western University, $750.
2016	WGRS and Teaching Assistant Scholarship, Western University, $35,000 per year.
2016	Ten Outstanding Graduates Scholarship, South China Normal University, ¥ 1,000.

2016 Zeng Yongyu Scholarship, South China Normal University, ¥ 600.

2015 National Graduate Student Scholarship, South China Normal University, ¥ 20,000.

2014 Graduate Research Award, South China Normal University, ¥ 3,000.

2012 Provincial Bronze Prize in 5th Small "National Challenge Cup", Hunan University of Science and Technology, ¥ 200.

2012 Advanced individual of Scientific Award/ Excellent Student, Hunan University of Science and Technology

SKILLS

Statistical software: R, Matlab, SPSS, Python
Experimental software: DMDX, E-Prime
EEG/ERP software: ERPLAB, EEGLAB
Document management software: Mendeley, Endnote
Advanced Statistical Methods: GLME, LME, easyNet