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The origins of backward priming effects in logographic scripts for four-character words[☆]

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ABSTRACT

Yang, Chen, Spinelli, and Lupker (2019) reported a large masked priming effect in a Chinese lexical-decision task using prime-target pairs in which the primes were presented in a backward (right-to-left) orientation (e.g., 说来的总-总的来说) (a “backward” priming effect). The question addressed here is whether this effect is truly an orthographic priming effect or is, to some degree, morphologically/meaning- or syllabic/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. As backward priming effects do not emerge in English, these results suggest that the orthographic coding process is quite different for Chinese versus English readers. Specifically, they support the conclusion that the orthographic coding process for Chinese readers codes character positions in a quite flexible fashion. Issues concerning the generalizability of current models of orthographic coding in alphabetic languages, as well as implications for models of Chinese word recognition, are discussed.

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, Marcet, & Fernández-López, 2018; Witzel, Qiao, & Forster, 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

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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, 2012; 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 et al., 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.’s 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, and 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 structrues 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 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) model 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 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, Davis & New, 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.'s (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 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 1. Therefore, Experiment 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, 4 and 5 reprsented an attempt to evaluate the potential contribution of meaning-based priming to Yang, Chen et al.'s (2019) backward priming effect. Both Experiments 3 and 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 was to deterimine whether the same was true in Chinese. To that end, Gu et al. (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 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 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 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 4, the stimuli from Experiment 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 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 1 and 4 would be expected. A null (or small) priming effect in Experiment 4 would be more consistent with the idea that at least part of the effect in Experiment 1 was meaning-based.

To again look ahead, similar size priming effects were found in Experiments 1 and 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 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 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.

Experiment 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 signed by each 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).

We 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 comprise 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 - (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 (1 2 0) 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, and Zuccolotto (2002)). The stimuli were presented on a 19-inch CRT monitor using a refresh rate of 60HZ (16.67 ms). The screen resolution was 1280 × 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).

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, more than 3 standard deviations from the participant's mean latency and from incorrect trials (7.6% 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, Mächler, Bolker, & Walker, 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, Davidson, & Bates, 2008). The emmeans package was used for post-hoc analyses (Lenth, 2018). Before running the model, R-default treatment contrasts were altered to sum-to-zero contrasts (Levy, 2014; Singmann & Kellen, 2017). 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, we 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 1. Our method for determining the appropriate level of power in each of the experiments was based on Brysbaert and Stevens (2018) suggestion that there should be at least 1600 trials in each condition.

Table 1

Mean Lexical Decision Latencies (RTs, in Milliseconds) and Percentage Error Rates for Words in Experiment 1 (standard deviations in parentheses).

	Syllabic condition		Backward condition	
	RT	%E	RT	%E
Related	719(85)	6.4(5)	660(81)	3.5(4)
Control	724(83)	6.7(5)	714(84)	5.7(6)
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, $\beta = 17.475$, $SE = 1.644$, $z = 10.63$, $p < .001$, and there was also a significant main effect of Relatedness, $\beta = -15.943$, $SE = 3.775$, $z = -4.224$, $p < .001$. Responses were faster overall in the backward conditions and for related primes. The interaction between Prime Type and Relatedness was also significant, $\beta = 12.707$, $SE = 1.581$, $z = 8.04$, $p < .001$, 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, $\beta = -6.47$, $SE = 8.10$, $z = -0.80$, $p = .424$, however, there was a highly significant backward priming effect, $\beta = -57.30$, $SE = 8.27$, $z = -6.93$, $p < .001$.

In the error rate analysis, the main effect of Prime Type was significant, $\beta = -0.225$, $SE = 0.052$, $z = -4.37$, $p < .001$, due to the fact that there were more errors in the syllabic conditions (6.5%) than in the backward conditions (4.6%). There was also a main effect of Relatedness, $\beta = 0.171$, $SE = 0.08$, $z = 2.13$, $p = .033$, with 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, $\beta = -0.126$, $SE = 0.052$, $z = -2.43$, $p = .015$. In the post-hoc analyses, targets following backward related primes elicited fewer errors (3.5%) than targets following backward unrelated primes (5.7%), $\beta = 0.593$, $SE = 0.204$, $z = 2.91$, $p = .004$. In the syllabic conditions, the error rate was similar for targets following backward syllabically related (6.4%) vs backward syllabically unrelated primes (6.7%), $\beta = 0.089$, $SE = 0.177$, $z = 0.50$, $p = .616$.

We 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. We used Jeffreys (1961) classification scheme to help interpret the results of Bayes Factor analysis. In Experiment 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, we 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.

Discussion

The results of Experiment 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 & Shu, 2001). Therefore, in Experiment 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 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.

Experiment 2

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 1 with the one new target and its primes being created as a replacement for the duplicated target in Experiment 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. These were (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 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 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 1 were used in Experiment 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 1.

Procedure. The procedure was the same as in Experiment 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.

Results

Response latencies less than 300 ms, more than 3 standard deviations from the participant’s mean latency and from incorrect trials (5.4% 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 2 are shown in Table 2 for the word targets.

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 model with a Relatedness effect (the alternative hypothesis H_1). The other details are the same as in Experiment 1. In Experiment 2, The Bayes Factor, $BF_{01} = 56.19$, in Jeffreys (1961) classification scheme, indicates “strong” evidence for the absence of a Relatedness effect.

We also contrasted the backward syllabic priming effect in Experiment 1 with the forward syllabic priming effect in Experiment 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* greater than 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

Table 2
Mean Lexical Decision Latencies (RTs, in Milliseconds) and Percentage Error Rates for Words in Experiment 2 (standard deviations in parentheses).

Condition	RT	%E
Syllabic related prime	695(82)	3.4(5)
Syllabic unrelated prime	697(78)	3.6(5)
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.

produced using primes in the backward orientation than in the forward orientation.

Discussion

The results of Experiment 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 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 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, 4 and 5 were attempts to evaluate the question of whether the backward priming effect might have a meaning-based component. Unfortunately, due to the nature of Chinese (i.e., each character is a morpheme), 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 and 4, therefore, adopted a slightly different approach to trying to answer this question, one involving a change in the experimental task.

Experiment 3

In Experiments 3 and 4, the task used was the masked priming same-different task. Priming in this task appears to be primarily 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 et al., 2015; 2018). Most imporantly, 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 et al., 2011) and Hebrew (Kinoshita et al., 2012).[1] At this point, however, there are no demonstrations that such is the case in Chinese.

Experiment 3 was an attempt to examine this issue in Chinese, using the manipulation reported by Gu et al. (2015). As noted above, 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 (i.e., a meaning component of the target). 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. (2015) result suggests is that there is little evidence for transposed morphological priming in Chinese in a lexical decision task when using two-character words. More centrally to present purposes, however, what Gu et al.'s manipulation provides is a means of evaluating whether the masked priming same-different task is immune to morphological/meaning-based 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 our four-character Chinese words in Experiment 4. Experiment 3 was, therefore, carried out to test whether the masked priming effect in the same-different task for Chinese readers has a morphological/meaning-based component by using Gu et al.'s stimuli and manipulations.

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, we 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 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 ($M = 1.57$, $SD = 1.26$), $p > .10$. Similarly, the radical stroke count for single-morpheme words ($M = 20.75$, $SD = 3.95$) is virtually identical to that for the two-morpheme words ($M = 21.58$, $SD = 3.77$), $p > .10$. Also, the radical frequency for single-morpheme words ($M = 12.57$, $SD = 25.87$) is virtually the same as that for the two-morpheme words ($M = 12.69$, $SD = 30.25$), $p > .10$. Two different types of primes for each word target were used, (1) transposed character primes (e.g., 拖沓(AB)-沓拖(BA) - 拖沓(AB)) and (2) unrelated primes (e.g., 拖沓(AB)- 肴肿(EF) - 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 1. The radical frequency and radical stroke counts for the four types of primes did not differ from each other, both *ps* greater than 0.10.

We 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, we did not manipulate the morphemic status of the targets, because there is only a limited number of two-character single-morpheme words in Chinese. Each different target was primed by either a transposed prime (e.g., 衰减-率表(DC) - 表率(CD)) or an unrelated prime (e.g., 房产 - 身面 - 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 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 (16.67 ms). The screen resolution was 1360 × 768. 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 1.

Results

Response latencies less than 300 ms, more than 3 standard deviations from the participant's mean latency and from incorrect trials (10.8% of the data) were excluded from the latency analyses. The data

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

Table 3
Mean Lexical Decision Latencies (RTs, in Milliseconds) and Percentage Error Rates for Targets on "same" trials in Experiment 3 (standard deviations in parentheses).

	Single-morpheme condition		Two-morpheme condition	
	RT	%E	RT	%E
Related	517(70)	5.1(5)	525(87)	6.5(6)
Control	581(79)	11.5(7)	585(73)	12.4(9)
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.

from "different" targets were not analyzed due to the fact that those targets were not counterbalanced across prime type. 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 1. The mean RTs (in ms) and percentage error rates for Experiment 3 are shown in Table 3 for the "same" targets.

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 1. The Bayes Factor, $BF_{01} = 81.36$, which, in Jeffreys's (1961) classification scheme, indicates "strong" evidence for the null hypothesis (i.e., the absence of an interaction).

Discussion

The results of Experiment 3 are very similar to Gu et al. (2015) results obtained in a masked priming lexical decision task. Equally importantly, for purposes of the procedure used in Experiment 4, these results support the conclusion derived from the literature (Duñabeitia et al., 2011; Kinoshita et al., 2012) that the masked priming same-difference task is not sensitive to morphologically-based priming. As such, this task using the four-character stimuli from Experiment 1 can provide a basis for examining the question of whether the priming effects both reported by Yang, Chen et al. (2019) and observed in Experiment 1 have a morphological/meaning basis.

Experiment 4

In Experiment 4, the task used was again the masked priming same-different task, with the stimuli being essentially the same as those in Experiment 1. As Experiment 3 and the previous literature suggest, priming in the same-different task has no morphological/meaning-based component. Therefore, by virtue of the fact that, as Experiments 1 and 2 have demonstrated, phonological priming does not emerge for four-character Chinese primes and targets, the priming observed in Experiment 4 should be entirely orthographically-based. As a result, the effect that emerges in Experiment 4 should be the same size as the effect in Experiment 1 if the effect in Experiment 1 is also entirely orthographically-based.

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 1 with one additional target (and its primes) being added to replace the target that was presented twice in Experiment 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 4. Two different types of primes for each word target were used, (1) backward primes (e.g., 有所不同(ABCD) - 同不所有(DCBA) - 有所不同(ABCD)); and (2) unrelated primes (e.g., 有所不同(ABCD) - 灭自生自(EFGH) - 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 2.

We 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). We 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., 掩耳盗铃(ABCD) - 铃盗耳掩(DCBA) - 火眼金睛) or an unrelated prime (e.g., 世风日下(ABCD) - 生而运应(EFGH) - 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 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.

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[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 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 the results on "same" trials.

Table 4
Mean Lexical Decision Latencies (RTs, in Milliseconds) and Percentage Error Rates for targets on "same" trials in Experiment 4 (standard deviations in parentheses).

Condition	RT	%E
Backward prime	603(63)	4.1(3)
Unrelated prime	656(65)	9.4(7)
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.

Results

Response latencies less than 300 ms, more than 3 standard deviations from the participant's mean latency and from incorrect trials (8.9% of the data) were excluded from the latency analyses. The data from "different" trials were not analyzed due to the fact that those targets 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"), 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", control = glmerControl(optimizer = "bobyqa", optCtrl = list (maxfun = 1e6))). The other details were same as in Experiment 1. The mean RTs (in ms) and percentage error rates for Experiment 4 are shown in Table 4 for the "same" targets.

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%).

We further contrasted the priming effect in Experiment 4 with the backward priming effect in Experiment 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, $SE = 3.276$, $z = -0.102$, $p = .919$. In the error rate analysis, the two main effects of Task and Relatedness were also significant, ß = 0.215, $SE = 0.110$, $z = 1.96$, $p = .05$; ß = 0.402, $SE = 0.081$, $z = 4.97$, $p < .001$, respectively, 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 1. In Experiment 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).

Discussion

In Experiment 4, we 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 1 and 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.

Experiment 5

Even though both Experiments 3 and 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 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 1 and 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 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

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[3] The main purpose of the repetition prime conditions was that, in case we failed to observe any differences among the other conditions, the expected shorter latencies in the repetition prime conditions would indicate that the experimental design was sensitive enough to pick up true differences. Indeed, the repetition prime conditions were the fastest conditions for both script types.

Table 5
Potential sources of priming from the middle two characters in the TC, Hiragana TC and SC primes in Experiment 5.

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

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 5). Therefore, if TC priming for logographic words is at all meaning based, one would expect a larger TC priming effect for the Kanji targets.

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 1 and 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 H.-C. 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 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 5). 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 5). This contrast is the contrast between the Hiragana TC primes and the TC primes. As indicated in Table 5, 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.

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, we chose only four-character Kanji words with second and third characters that are only pronounced with a single mora (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 we attempted 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.

We created 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

(16.67 ms). The screen resolution was 800 × 600. The general procedure was the same as in Experiment 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-16/16 T(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).

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, more than 3 standard deviations from the participant’s mean latency and from incorrect trials (8.4% 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 1. The mean RTs (in ms) and percentage error rates for Experiment 5 are shown in Table 6 for the word targets.

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 involving 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 × 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, $\chi^2 = 19.54$, $p < .001$. 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/meaning-based 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 the TC condition, with there being no significant difference among the other three 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.

Table 6
Mean Lexical Decision Latencies (RTs, in Milliseconds) and Percentage Error Rates for Words in Experiment 5 (standard deviations in parentheses).

	Kanji		Katakana	
	RT	%E	RT	%E
Transposed Character (TC) prime	560(117)	4.6(6)	564(114)	5.3(5)
Hiragana TC prime	576(110)	5.6(7)	579(115)	8.2(8)
Substituted Character (SC) prime	585(132)	6.5(7)	606(120)	11.3(9)
Repetition prime	552(117)	4.3(6)	555(125)	4.9(6)

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.

Discussion

The initial idea behind Experiment 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 1 and 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 5). 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 non-significant 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 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 1 and 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 would receive 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.

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 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 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, involving a masked priming same-different task, indicated that task is not sensitive to morphological relationships, which set the stage for Experiment 4. Experiment 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 1 (54 ms), suggesting the Yang, Chen et al.'s backward priming effect, replicated in Experiment 1, was most likely entirely an orthographically-based effect. Experiment 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, Wu, & Chen, 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 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 1) than the other (i.e., the same-different task in Experiment 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 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 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 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 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 parameters that reflect 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.

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.

CRediT authorship contribution statement

Huilan Yang: Conceptualization, Methodology, Software, Formal analysis, Resources, Data curation, Writing - original draft, Writing - review & editing. **Yasushi Hino:** Methodology, Software, Resources, Data curation, Writing - original draft, Writing - review & editing. **Jingjun Chen:** Software, Resources, Data curation, Funding acquisition. **Masahiro Yoshihara:** Software, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing. **Mariko Nakayama:** Writing - original draft, Writing - review & editing. **Junyi Xue:** Software, Resources, Data curation. **Stephen J. Lupker:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jml.2020.104107.

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