Journal of Experimental Psychology:
Learning, Memory, and Cognition
2017, Vol. 43, No. 7, 1140–1146

0278-7393/17/$12.00 http://dx.doi.org/10.1037/xlm0000365

RESEARCH REPORT

Alternating-Script Priming in Japanese: Are Katakana and Hiragana Characters Interchangeable?

Manuel Perea
Universitat de València

Mariko Nakayama
Waseda University and Rikkyo University

Stephen J. Lupker
University of Western Ontario

Models of written word recognition in languages using the Roman alphabet assume that a word's visual form is quickly mapped onto abstract units. This proposal is consistent with the finding that masked priming effects are of similar magnitude from lowercase, uppercase, and alternating-case primes (e.g., beard–BEARD, BEARD–BEARD, and BeArD–BEARD). We examined whether this claim can be readily generalized to the 2 syllabaries of Japanese Kana (Hiragana and Katakana). The specific rationale was that if the visual form of Kana words is lost early in the lexical access process, alternating-script repetition primes should be as effective as same-script repetition primes at activating a target word. Results showed that alternating-script repetition primes were less effective at activating lexical representations of Katakana words than same-script repetition primes—indeed, they were no more effective than partial primes that contained only the Katakana characters from the alternating-script primes. Thus, the idiosyncrasies of each writing system do appear to shape the pathways to lexical access.

Keywords: lexical access, masked priming, abstract units

Current models of written word recognition in languages using the Roman alphabet assume that information about the visual form of the word's component letters is rapidly lost in the early stages of processing, so that the critical stages in lexical access are based on the activation of abstract letter units (Dehaene, Cohen, Sigman, & Vinckier, 2005; Grainger, Rey, & Dufau, 2008). Consistent with this view, previous research has reported similar size priming effects for uppercase word targets that are preceded by a masked lowercase repetition prime (i.e., one in which the letters are nominally, but not physically, the same; e.g., beard–BEARD) versus a masked uppercase repetition prime (i.e., one in which the letters are physically the same; e.g., BEARD–BEARD) in lexical decision experiments (Jacobs, Grainger, & Ferrand, 1995; Perea, Jiménez, & Gomez, 2014; see Vergara-Martínez, Gómez, Jiménez, & Perea, 2015, for electrophysiological evidence). Furthermore, and most relevant to the present research, alternating-case repetition primes (BeArD–BEARD) have been shown to be as effective as lowercase repetition primes (beard–BEARD) in masked priming lexical decision experiments (Forster, 1998; Perea, Vergara-Martínez, & Gomez, 2015). Similarly, Brysbaert, Speybroeck, and Vanderelst (2009) found that alternating-case primes were as effective as lowercase primes in a masked associative-priming lexical decision experiment (e.g., similar word identification times for eRrOr–MISTAKE and error–MISTAKE). In summary, empirical evidence in languages using the Roman alphabet strongly suggests that, during visual word recognition, there is a fast mapping of the visual form of the words' component letters onto their corresponding abstract letter representations (see Carreiras, Armstrong, Perea, & Frost, 2014, for a review).

An important question is how far this conclusion about the abstract nature of letter/character-level representations can be generalized. That is, although the lowercase–uppercase distinction in the Roman alphabet is somewhat idiosyncratic in that it is absent in most non-Western languages, a number of other languages do contain pairs of letters/characters that could, in theory, map onto the same abstract letter/character-level representation. One such language is Japanese. In addition to its logographic Kanji characters, Japanese has two Kana syllabaries, Katakana and Hiragana, with both of these syllabaries having characters with direct correspondences to Japanese syllables (e.g., Hiragana: た, ち, つ, て,

This article was published Online First January 23, 2017.

Manuel Perea, Departamento de Metodología, Facultad de Psicología, Universitat de València; Mariko Nakayama, Department of Psychology, Waseda University, and College of Contemporary Psychology, Rikkyo University; Stephen J. Lupker, Department of Psychology, University of Western Ontario.

This research was partly supported by the Spanish Ministry of Economy and Competitiveness (Grant PSI2014-53444-P to Manuel Perea), the Japan Society for the Promotion of Science Grant-in-Aid for Scientific Research (Grant 15K04194 to Mariko Nakayama), and the Natural Sciences and Engineering Research Council of Canada (Grant A6333 to Stephen J. Lupker).

Correspondence concerning this article should be addressed to Manuel Perea, Departamento de Metodología, Universitat de València, Avenida de Blasco Ibáñez, 21, 46010 Valencia, Spain. E-mail: mperea@uv.es

と; Katakana: タ, チ, ツ, テ, ト: /ta/, /ti/, /tu/, /te/, /to/, respectively).[1] That is, any given syllable can be written in either script, meaning that the parallel characters in the two scripts could be essentially interchangeable in the same way that lowercase and uppercase Roman letters are. Hence, one could imagine that those parallel characters would share abstract character-level representations.

What needs to be noted, however, is that the parallels of Katakana and Hiragana to upper- and lowercase letters in Roman script are far from perfect. For example, the use of the two Japanese scripts follows precise rules. On the one hand, Hiragana is usually used to complement Kanji words (e.g., postpositional particles, as in日曜日に [Sunday]; inflections, as in 高い [high]) although it can also be used transcribe some content words (e.g., うちわ, a fan). On the other hand, Katakana is used primarily to transcribe loan words (e.g., サッカー, soccer). As a result, only a small percentage of Japanese words exist that appear in both a Hiragana form and a Katakana form (and no words are ever written in a combination of the two scripts).

It is certainly possible that these precise rules of usage may hinder/prevent the development of abstract character-level representations. For instance, Polk et al. (2009) suggested that abstract letter representations develop as a result of readers associating a set of visually different letters occurring in the same context. That is, by learning that "restaurant," "Restaurant," and "RESTAURANT" are the same word (i.e., they all have the same referent), uppercase and lowercase versions of the same letter would become mapped onto the same underlying representation. Consistent with the earlier discussion, however, in the case of Japanese Kana, only the Katakana form "レ ストラン" (re.su.to.ra.n) of "restaurant" would appear in Japanese text, whereas the mixed form "**れ**ストラン" and the Hiragana form "**れすとらん**" would not (the characters in boldface type are Hiragana characters). Therefore, logically, a reasonable argument could be made that Katakana and Hiragana characters will not become mapped onto the same character-level representations.

In an initial attempt to examine this question empirically, using a masked priming lexical-decision task, Pylkkänen and Okano (2010) found that word identification times to Katakana words were similar when the prime was a repetition Katakana prime (i.e., physically and phonologically the same; e.g., ピーマ ン–ピーマ ン) or a Hiragana transcription prime (i.e., phonologically but not physically the same; e.g., **ぴーまん**–ピーマ ン).[2] Pylkkänen and Okano interpreted their results as indicating that there are shared abstract character-level representations for Hiragana and Katakana characters and concluded that "sound identity is what determines orthographic identity: as long as two symbols express the same sound, our minds represent them as part of the same character/letter" (p. 1).

Subsequently, using a go/no-go semantic categorization task with Kana-written words while recording event-related potentials (ERPs), Okano, Grainger, and Holcomb (2013) were also able to provide a comparison of same-script repetition priming (both Hiragana–Hiragana and Katakana–Katakana pairs; Experiment 1) versus cross-script repetition priming (Katakana-Hiragana and Hiragana-Katakana pairs; Experiment 2). Results showed reasonably similar patterns of masked repetition priming across several ERP components (N250 and N400) in the two experiments; a second result that would seem to be consistent with the notion of shared character-level representations.

Okano et al. (2013), however, also noted that there were differences between cross-script and same-script pairs in terms of the time course of activation. That activation was slower for the cross-script pairs than for the same-script pairs. Okano et al. concluded, "processing words in a syllabary script can be understood in terms of the same basic mechanisms thought to be involved in word recognition in alphabetic scripts" (p. 403), in that recognition of Katakana words, like that of alphabetic words, involves sequential processing from the feature, sublexical, and lexical levels to the semantic level. However, they did not conclude that Hiragana and Katakana characters have shared abstract character-level representations. Rather, they interpreted the different time courses for their same- versus cross-script conditions as evidence that the processing of different scripts does differ "given the different orthographic representations across scripts" (p. 398). Specifically, whereas same-script repetition priming would be presumed to benefit from shared orthographic and phonological representations, cross-script repetition priming would benefit only from shared phonological representations (and thus the cross-script primes would activate targets more slowly than [although possibly as effectively as] same-script primes). The important point here is that Okano et al. took a different position than Pylkkänen and Okano (2010) by suggesting that cross-script primes do not map on to the same character-level representations as same-script primes.

In essence, although previous studies do indicate that the general mechanisms underlying word recognition for Kana words may be similar to those for alphabetic words, based on, for example, Pylkkänen and Okano's (2010) demonstration that cross-script primes are as effective as same-script primes in masked priming lexical decision experiments, the nature of the character-level representations for the two types of Kana scripts is still a subject of debate. The purpose of the present research was, therefore, to examine the underlying character-level representations of the Japanese Kana scripts, using the character alternation masked priming procedure.

If Pylkkänen and Okano (2010) are correct in that the visual form of Hiragana and Katakana words is lost early in processing, as appears to happen with case information in the Roman alphabet (see Vergara-Martínez et al., 2015, for electrophysiological evidence), alternating-script repetition primes in masked priming should be as effective as same-script repetition primes at activating a target word (i.e., レ **す**ト**ら**ン–レ ストラン ["re.su.to.ra.n"—where the second and fourth character in the primes are in Hiragana and the others are in Katakana] and レ ストラン– レ ストラン [where all characters in both prime and target are in Katakana] should yield similar masked priming effects). This result would be consistent not only with the idea that the pathways for lexical access involve the same basic mechanisms in the Roman and Kana writing systems but also that the two Kana scripts involve shared character-level representations.

What should also be noted is that there is another salient feature of Japanese that may affect processing of alternating-script stimuli in the early stages of word processing. Unlike in Western languages, Japanese is an unspaced writing system. Hence, it is common to see

[1] As Katakana and Hiragana are syllabaries, the characters in these scripts provide sound, but not meaning, information.

[2] Although this is an example drawn directly from Pylkkänen and Okano (2010), a Japanese reader would recognize that the dash in **ぴーまん** is actually a Katakana character rather than a Hiragana character.

contiguous characters in Hiragana and Katakana. When one encounters contiguous characters in Hiragana and Katakana, however, the direct implication is that readers are encountering a word boundary (i.e., those characters form parts of different words because, as noted, no Japanese words contain both Katakana and Hiragana characters). As such, an alternating-script Japanese word (e.g., レ すトらン) would not simply look highly unusual to a native reader of Japanese (as happens with alternating-case words like BeArD for English readers), but this mixture of Kana characters would, possibly, be initially parsed as if characters from the different scripts belong to different words. In theory, this reason alone may cause alternating-script primes to produce a different pattern of results than same-script primes, although as will be discussed subsequently, if both types of Kana characters are mapped onto abstract character-level representations, one would still expect that alternating-script primes would be better than primes that do not contain the relevant Hiragana characters.

In the present research, we conducted two masked priming lexical decision experiments. In Experiment 1, each target in Katakana was preceded by a repetition prime in Katakana (e.g., レ ストラン–レ ストラン), a repetition prime in alternating script (e.g., レ すトらン–レ ストラン), or an unrelated prime (either in Katakana or in alternating script; e.g., イヤリング–レ ストラン or イやリんグ–レ ストラン).[3] As in prior experiments, and to avoid visual continuity of primes and targets, we used a 16.6-ms mask between the 33.3-ms prime and the target stimulus (see Perea et al., 2015, for a discussion). Experiment 2 was a follow-up experiment in which the Hiragana characters were replaced by asterisks.

Experiment 1

Method

Participants. Forty-eight students from Waseda University (Tokyo, Japan) participated in this experiment. All of them were native Japanese speakers/readers with normal or corrected-to-normal vision.

Stimuli. The target words were 120 five-character words typically written in Katakana ($M = 5.8/6.0$ on the Orthographic Validity Ratings Scale according to Amano & Kondo, 2003). The mean written word frequencies of the targets was 2.1 occurrences per million (Amano & Kondo, 2003). Targets, on average, had 1.0 neighbors according to Amano and Kondo (2003). Each target was preceded by one of four types of primes: (1) Katakana repetition (e.g., レ ストラン–レ ストラン); (2) Katakana unrelated (イヤリング–レ ストラン); (3) alternating-script repetition (e.g., レ すトらン–レ ストラン); or (4) alternating-script unrelated (e.g., イやリんグ–レ ストラン). Alternating-script primes in the repetition condition were created by replacing the second and the fourth characters in the Katakana primes with the appropriate Hiragana characters. Unrelated prime–target pairs were created by re-pairing prime–target pairs in such a way that the prime and target did not contain the same characters in the same relative positions. Care was taken to make sure that the unrelated primes were not phonologically or semantically related to their targets. Words containing the character "へ" in the second and fourth character positions were avoided in selecting the stimuli, because that character looks very similar in its Katakana and Hiragana forms.

One hundred and twenty pronounceable five-character Katakana nonwords were also selected (e.g., ラスノモス) for the purposes of the lexical-decision task. As was the case with the word targets, four types of primes primed each nonword target: Katakana repetition, Katakana unrelated, alternating-script repetition, or alternating-script unrelated. The unrelated primes were created in the same way as was done for the word targets. Four counterbalanced presentation lists were created, so that within a list, each target was primed by only one type of prime, but across the four lists, each target was primed by each of the four types of primes. One quarter of the participants received each list.

Procedure. Participants were tested individually in a quiet room. The stimulus presentation was controlled by DMDX software (Forster & Forster, 2003) using a desktop computer with a 60-Hz CRT monitor. Each trial started with a forward mask (######) for 500 ms, which was immediately replaced by a prime presented for 33.3 ms. The mask (######) was then presented for 16.6 ms and was followed by the target stimulus. The target remained on the computer screen until the participant made a response. Primes and targets were both presented in 14-point Microsoft Mincho font. Participants were asked to decide whether the target stimulus was a real Japanese word or not as fast and accurately as possible and respond by pressing either the "Yes" (word) or "No" (nonword) button on a response box in front of them. Participants received 16 practice trials at the beginning of the experimental session, not involving any of the stimuli used in the experiment proper.

Results and Discussion

Correct response times faster than 250 ms or slower than 1,300 ms were removed as outliers (0.1% and 0.4% of the data for the word and nonword targets, respectively). Two participants (one participant due to high error rates, >20%, and the other due to overall slow responding, >2.5 *SD* slower than the group mean reaction time [RT]) were replaced by two new participants while maintain the counterbalancing of the lists. The correct response latency data were analyzed by using linear mixed effects (LME) models using *lme4* (Bates, Mächler, Bolker, & Walker, 2015) and the *lmerTest* package (Kuznetsova, Brockhoff, & Christensen, 2014) in R (R Core Team, 2015). Prior to the analyses, raw RT was transformed by using the transformation −1,000/RT to meet the Gaussian assumption required by the LME analyses. The initial model included Prime Type (Katakana vs. Alternating), Repetition (Repeated vs. Unrelated) and the interaction between the two factors as fixed factors and by-subject and by-item intercepts and slopes for Prime Type, Repetition, and their interaction terms as random factors (the maximal model).[4] The two fixed factors were

[3] Katakana was chosen as the target script in these experiments because of the large number of five-letter Katakana-written words that could be used as targets. Most Hiragana-written words are less than four letters in length. Hence, the contrast between a same-script and an alternating-script prime for Hiragana targets would be a weak one (e.g., in English, the parallel contrast would be between CAT–CAT and CaT–CAT).

[4] In the initial analyses involving word targets in Experiments 1 and 2 (i.e., the analyses that included the two-way interaction), the maximal model did not converge. Therefore in each instance, we successively removed a random factor until the model converged and we report the statistical results based on the final reduced model, following the recommendation by Jaeger (2011).

respectively contrast coded by −0.5/+0.5. Errors were analyzed using a mixed-effects logistic model (Jaeger, 2008) with the same fixed factors and with by-subject and by-item intercepts as random factors. Table 1 shows the mean lexical decision times and error rates based on the by-subject means in Experiment 1.

Word targets. Lexical decision responses were slower for targets when primed by an alternating-script prime than when primed by a same-script prime (539 ms vs. 530 ms; $t = 3.35$, $p = .001$). The main effect of Repetition was also significant ($t = 7.85$, $p < .001$). Importantly, Prime Type and Repetition interacted significantly ($t = -2.40$, $p = .018$). This interaction reflects the fact that the repetition priming effect was greater with same-script primes (28 ms; $t = 7.18$, $p < .001$) than with alternating-script primes (17 ms; $t = 5.37$, $p < .001$). Further analysis also revealed that responses to target words following a same-script repetition prime were faster than those to targets following an alternating-script repetition prime (516 ms vs. 530 ms; $t = 4.07$, $p < .001$). In contrast, for unrelated trials, word identification times were similar when the prime was in the same script versus when the prime was in alternating script (a 3-ms difference; $t < 1$).

Error rates were higher for targets primed by alternating-script primes than by same-script primes (6.3% vs. 5.2%; $z = 2.42$, $p = .016$). The main effect of Repetition was not significant ($z = 1.33$, $p > .10$). The interaction between the two factors did not approach significance ($z < 1$).

Nonword targets. No significant effects were observed for response latency or for errors (all *t*s and *z*s < 1).

Experiment 1 showed that same-script primes were more effective than alternating-script primes at activating the target word: The magnitude of the repetition priming effect was greater in the same-script condition than in the alternating-script condition (28 vs. 17 ms, respectively). Nonetheless, given that alternating-script primes did produce a sizable repetition priming effect, one could certainly argue that the alternating-script primes were effective at activating the relevant character-level representations, implying that those representations are abstract in nature. However, one could also argue that the repetition priming effect with alternating-script repetition primes—which were always in the form of KHKHK (where *K* is Katakana and *H* is Hiragana)—was merely a masked form priming effect based on the three (out of five) Katakana characters shared by the prime and target. Previous research has shown significant facilitation priming from primes of this sort (e.g., Perry, Lupker, & Davis, 2008; Vergara-Martínez, Perea, Marín, & Carreiras, 2011) with the sizes of these effects, of course, being smaller than those for full repetition primes (Vergara-Martínez et al., 2011).

To evaluate these ideas, in Experiment 2, we compared an alternating-script priming condition with a new "partial priming" condition in which the Hiragana characters were replaced by an asterisk (i.e., a sign that does not resemble any Japanese character). The predictions are straightforward. If Hiragana characters in masked alternating-script primes are helpful because the underlying representations of Kana characters are abstract in nature, alternating-script primes should be more effective primes than partial primes. Alternatively, if Hiragana characters are represented differently than Katakana characters at the character level, one would not expect a difference between the alternating-script prime and partial prime conditions.

Table 1
Mean Lexical Decision Latencies (in Milliseconds) and Percentage Errors for Word and Nonword Targets in Each Condition in Experiment 1

Prime type	Katakana (レ ストラン—レ ストラン)	Script alternation (レ すトらン—レ ストラン)
	Word targets	
Repeated	516 (4.9%)	530 (5.8%)
Unrelated	544 (5.4%)	547 (6.7%)
Priming	28 (0.5%)	17 (0.9%)
	Nonword targets	
Repeated	583 (3.1%)	582 (2.6%)
Unrelated	583 (2.3%)	582 (3.1%)
Priming	0 (−0.8%)	0 (0.5%)

Experiment 2

Method

Participants. Forty-eight students from Waseda University (Tokyo, Japan) participated in this experiment. All of them were native speakers/readers of Japanese and had normal or corrected-to-normal vision. None of these individuals had participated in Experiment 1.

Stimuli. The targets were the same set of Katakana words used in Experiment 1. Each target was preceded by one of four types of primes: (1) partial repetition (e.g., レ∗ト∗ン–レ ストラン); (2) partial unrelated (イ∗リ∗グ-レ ストラン); (3) alternating-script repetition (e.g., レ すトらン–レ ストラン); or (4) alternating-script unrelated (e.g., イやりんグ–レ ストラン). The partial repetition primes were essentially unambiguous; very few other Katakana words could be generated based on these primes ($M = 0.23$). The same set of Katakana nonword targets used in Experiment 1 was also used. Similarly, each nonword target was also preceded by one of the four types of primes. The creation of prime–target pairs was the same as in the word target condition.

Procedure. The procedure, including the counterbalancing of primes and targets, was identical to that in Experiment 1.

Results and Discussion

Correct RTs faster than 250 ms or slower than 1,300 ms were removed as outliers (0.2% and 0.3% of the data both for word and nonword trials, respectively). As was the case in Experiment 1, two participants (one participant due to high error rates [>20%] and the other due to overall slow responding [>2.5 *SD* slower than the group mean RT]) were replaced by two new participants while maintain the counterbalancing of the lists. The remainder of the data were analyzed in the same way as in Experiment 1 although it should be noted that the fixed factor Prime Type now reflects the contrast between partial primes and alternating-script primes. Table 2 shows the mean lexical decision times and error rates based on the by-subject means in Experiment 2.

Word targets. Lexical decision responses were, on average, 8 ms slower in the alternating-script prime condition than in the partial prime condition (536 ms vs. 528 ms; $t = 2.96$, $p = .004$).

Table 2
Mean Lexical Decision Latencies (in Milliseconds) and Percentage Errors for Word and Nonword Targets in Each Condition in Experiment 2

Prime type	Partial (レ＊ト＊ン—レストラン)	Script alternation (レすとらン—レストラン)
	Word targets	
Repeated	522 (4.7%)	527 (4.4%)
Unrelated	535 (4.5%)	544 (7.4%)
Priming	13 (−0.2%)	17 (3.0%)
	Nonword targets	
Repeated	582 (2.2%)	575 (3.0%)
Unrelated	582 (2.2%)	577 (2.3%)
Priming	0 (0%)	2 (−0.7%)

The main effect of Repetition was also significant ($t = 5.98$, $p < .001$). There was no indication of an interaction between the two factors ($t = 1.15$, $p > .25$).

For errors, the main effect of Prime Type was significant ($z = 2.08$, $p = .038$). There also was a significant main effect of Repetition ($z = 2.36$, $p = .018$). Unlike in the response latency analysis, the two-way interaction between Prime Type and Repetition was significant ($z = 2.60$, $p = .010$). This interaction was due to the fact that whereas error rates were not significantly different for targets primed by the two different types of repetition primes (4.7% vs. 4.4%; $z < 1$), error rates were higher when targets were preceded by an unrelated alternating-script prime than when preceded by an unrelated partial prime (7.3% vs. 4.5%; $z = 3.47$, $p < .001$).

Nonword targets. The only significant effect observed was a main effect of Prime Type in the RT analysis ($t = -2.42$, $p = .018$): Responses were, on average, 6 ms slower when targets were preceded by partial primes than by alternating-script primes (582 ms vs. 576 ms). No other effects were significant (all ts and zs < 1).

For word targets, the magnitude of the masked priming effect was similar in magnitude for alternating-script primes and partial primes (17 vs. 13 ms, respectively), although there was a small, but significant, interaction in the error data due to the alternating-script unrelated condition showing more errors than all the other conditions (which had essentially identical error rates). Note also that there was an effect of prime type: word identification times were slower and error rates were higher for the word targets preceded by alternating-script primes than for the word targets preceded by partial primes. That is, it appears that the alternating-script condition did involve some cost, at least when compared to a partial prime condition.

General Discussion

In the Roman alphabet, lowercase primes, uppercase primes, and alternating-case primes have been shown to be equally effective at activating lexical representations using an experimental paradigm that taps early word processing (masked priming; Brysbaert et al., 2009; Forster, 1998; Perea et al., 2015), implying that both lower- and uppercase letters provide fast access to a word's abstract letter-level representations. Similarly, Pylkkänen and Okano (2010) found that Hiragana transcriptions of Katakana words were as effective as primes of Katakana target words as were Katakana prime words whereas Okano et al. (2013) found similar, but not identical, masked repetition priming effects for cross-script and same-script Kana word pairs in two ERP experiments. These data provide some support for the idea that the two types of Kana characters are quickly mapped into abstract character-level representations regardless of the specific syllabary (Hiragana or Katakana) in which they are presented—as appears to be true for letters in different cases in the Roman alphabet.

Here, we conducted two masked priming lexical decision experiments to more fully examine this question by asking to what extent alternating-script Katakana–Hiragana character primes activate common representations. The main findings can be summarized as follows: (a) alternating-script repetition primes were significantly less effective primes than same-script repetition primes (repetition priming effects: 17 vs. 28 ms, respectively; Experiment 1); and (b) alternating-script repetition primes were no more effective than partial primes that contained the same Katakana characters (priming effects: 17 vs. 13 ms, respectively; Experiment 2). The present results, therefore, indicate that, although there is a priming effect for Katakana targets from alternating-script Kana words (Experiments 1 and 2) it is likely due to the shared Katakana characters (レすとらン–レストラン) in the prime and target, a conclusion based on the fact that there was no difference between alternating-script primes and partial primes in which the Hiragana characters had been replaced with an asterisk (レ＊ト＊ン–レストラン) in Experiment 2. Hence the different Japanese Kana scripts do not appear to act in a way that is fully parallel to the actions of lower/uppercase letters in Roman script.

What, therefore, are the implications of the present results, combined with those from Pylkkänen and Okano (2010) and Okano et al. (2013), for the question of how characters are represented in Hiragana and Katakana? The most straightforward conclusion would be that this set of results indicates that, in Japanese, abstract units are shared at the lexical level, but not at the character level. That is, this conclusion is perfectly compatible with the idea that "repetition" primes activate the target's lexical representation regardless of what script the prime is written in. Thus, one would expect to find substantial priming effects from primes that are in different scripts than their targets (e.g., Okano et al., 2013; Pylkkänen & Okano, 2010; see also Hino, Lupker, Ogawa, & Sears, 2003, who showed a similar pattern using Kanji-Katakana word pairs). Importantly, however, this conclusion would not lead to the prediction of equivalent priming from same-versus alternating-script primes. The priming from alternating-script primes would be a combination of what the Katakana characters could contribute and what the Hiragana characters could contribute to activation of the target word's lexical representation. Given that the Hiragana pattern in these primes is just two characters in the middle of the word, one would not expect it to be too helpful. Thus, the results of Experiment 2 would be essentially what one would expect. That is, these ideas would be consistent with the fact that numerically, the alternating-script primes did produce a small, but nonsignificant (4 ms), priming advantage in the latency data relative to the partial primes and a small, but significant (3.2%), priming advantage in the error data.

Before accepting the conclusion that Hiragana and Katakana do not share character-level representations, one additional question should be asked. Might it be possible to explain the differences between our results and those of Pylkkänen and Okano (2010; and to a lesser degree, those of Okano et al., 2013) on the basis of the difficulty Japanese readers may have had processing mixed Katakana and Hiragana character strings as a unit? That is, would it be possible to argue that our inability to show equivalent priming from alternating-script versus same-script primes (a result that, if we had found it, would have supported the abstract character-level proposal) was due to the fact that our alternating-script stimuli were odd to Japanese readers in a way that alternating-case Roman letter stimuli are not? As noted, an alternating-script Kana string like レすトらン would not only be visually unfamiliar, since words like this never appear in Japanese writing, but also it may invoke a somewhat idiosyncratic processing response due to the fact that, in normal Japanese writing, the juxtaposition of Katakana and Hiragana characters marks a word boundary.

In order to substantiate an explanation of this sort, the data would need to show evidence that there actually was a negative impact of processing alternating-script primes. Experiment 2 does provide some evidence of such an impact. That is, in that experiment, alternating-script primes did produce a small, but significant, cost relative to partial primes, although only in the word data. Hence, those results would suggest that alternating-script primes may be slightly harder to deal with than partial primes. The results from Experiment 1, however, provide virtually no evidence that alternating-script primes were more difficult than same-script primes. The only prime-type difference observed in Experiment 1 was in the repeated condition for word targets, a difference that presumably results from the fact that same-script primes are better primes than alternating-script primes. In contrast, there was no prime-type difference in the unrelated condition, the condition that is immune to the impact of the repetition manipulation. Hence, it seems unlikely that an account based on the unusualness of alternating-script primes to Japanese readers could explain why those primes were less effective than same-script primes.

One final point to note about our experimental manipulations is that the two related prime types in both experiments provided no incorrect phonological information. Most important, the same-script and alternating-script repetition primes had identical phonologies (i.e., they were identical to those of the targets) in Experiment 1. Nonetheless, the alternating-script repetition primes produced slower responses and higher errors than the same-script repetition primes in that experiment. The fact that different latencies were produced by primes with identical phonologies implies that the phonological codes created by the primes likely played little role in producing the priming effects observed in Experiment 1. This claim is, of course, supported by the results of Experiment 2, as the alternating-script repetition primes, having phonological codes that were identical to those of their target, did not facilitate target processing relative to the partial primes, primes that were not fully phonologically identical to their targets (see Perea & Pérez, 2009, for a similar claim). This apparent lack of an impact of phonology in the present experiments does appear to be hard to reconcile with Pylkkänen and Okano's (2010) conclusion that "sound identity is what determines orthographic identity: as long as two symbols express the same sound, our minds represent them as part of the same character/letter" (p. 1).

What, then, are the implications of the present findings for models of written word recognition? In the Roman alphabet, Dehaene et al. (2005) and Grainger et al. (2008) argued that there is a fast conversion of the visual form of the words' constituent letters into abstract letter units. This statement is consistent with the presence of masked priming effects of similar size for beard–BEARD, BEARD–BEARD, and BeArD–BEARD (Forster, 1998; Perea et al., 2014, 2015). Pylkkänen and Okano (2010) and Okano et al. (2013) found similar masked repetition priming effects for Hiragana–Katakana and for Katakana–Katakana word pairs in Japanese. Although Okano et al. (2013) results did not lead them to conclude that characters in the two scripts shared abstract representations, they did suggest that their findings do "provide support for the hypothesis that visual word recognition involves a generalizable set of neurocognitive processes that operate in similar manners across different writing systems" (p. 390). The fact that script alternation in Kana does not behave as case alternation in the Roman alphabet behaves, however, does imply that what happens with the two Kana scripts in Japanese is not identical to what happens in Roman letter languages. In particular, it does seem that characters in the two scripts do not share abstract character-level representations, which means that the route to lexical access does differ depending on whether the word is written in Katakana or Hiragana.

In summary, the main aim of the current research was to examine whether a word's constituent characters in alternating-script Japanese Kana are quickly mapped onto an abstract common character-level representations, allowing equal repetition priming from same-script versus alternating-script primes. We found that, unlike alternating-case words in the Roman alphabet, alternating-script Kana character strings are not particularly effective at activating lexical representations. Unsurprisingly, therefore, theorists will still need to consider the idiosyncrasies of each writing system when modeling the pathways to lexical access.

References

Amano, N., & Kondo, H. (2003). *Nihongo no Goi Tokusei. NTT database series* (Dai 2 ki; 7 kan, CD-Rom version) [Lexical characteristics of Japanese language. NTT database series (No. 2; Vol. 7, CD-Rom version)]. Tokyo, Japan: Sanseido.

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

Brysbaert, M., Speybroeck, S., & Vanderelst, D. (2009). Is there room for the BBC in the mental lexicon? On the recognition of acronyms. *Quarterly Journal of Experimental Psychology, 62,* 1832–1842. http://dx.doi.org/10.1080/17470210802585471

Carreiras, M., Armstrong, B. C., Perea, M., & Frost, R. (2014). The what, when, where, and how of visual word recognition. *Trends in Cognitive Sciences, 18,* 90–98. http://dx.doi.org/10.1016/j.tics.2013.11.005

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

Forster, K. I. (1998). The pros and cons of masked priming. *Journal of Psycholinguistic Research, 27,* 203–233. http://dx.doi.org/10.1023/A:1023202116609

Forster, K. I., & Forster, J. C. (2003). DMDX: A windows display program with millisecond accuracy. *Behavior Research Methods, Instruments & Computers, 35,* 116–124. http://dx.doi.org/10.3758/BF03195503

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

Grainger, J., Rey, A., & Dufau, S. (2008). Letter perception: From pixels to pandemonium. *Trends in Cognitive Sciences, 12,* 381–387. http://dx.doi.org/10.1016/j.tics.2008.06.006

Hino, Y., Lupker, S. J., Ogawa, T., & Sears, C. R. (2003). Masked repetition priming and word frequency effects across different types of Japanese scripts: An examination of the lexical activation account. *Journal of Memory and Language, 48,* 33–66.

Jacobs, A. M., Grainger, J., & Ferrand, L. (1995). The incremental priming technique: A method for determining within-condition priming effects. *Perception & Psychophysics, 57,* 1101–1110. http://dx.doi.org/10.3758/BF03208367

Jaeger, T. F. (2008). Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. *Journal of Memory and Language, 59,* 434–446. http://dx.doi.org/10.1016/j.jml.2007.11.007

Jaeger, T. F. (2011, June 25). More on random slopes and what it means if your effect is no longer significant after the inclusion of random slopes [Web log message]. Retrieved from https://hlplab.wordpress.com/2011/06/25/more-on-random-slopes/

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2014). *lmerTest: Tests for random and fixed effects for linear mixed effect models (lmer objects of lme4 package).* R package (version 2. 0–29). Retrieved from http://Cran.r-project.org/package=lmerTest

Okano, K., Grainger, J., & Holcomb, P. J. (2013). An ERP investigation of visual word recognition in syllabary scripts. *Cognitive, Affective & Behavioral Neuroscience, 13,* 390–404. http://dx.doi.org/10.3758/s13415-013-0149-7

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

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

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

Perry, J. R., Lupker, S. J., & Davis, C. J. (2008). An evaluation of the interactive-activation model using masked partial-word priming. *Language and Cognitive Processes, 23,* 36–68. http://dx.doi.org/10.1080/01690960701578112

Polk, T. A., Lacey, H. P., Nelson, J. K., Demiralp, E., Newman, L. I., Krauss, D. A., . . . Farah, M. J. (2009). The development of abstract letter representations for reading: Evidence for the role of context. *Cognitive Neuropsychology, 26,* 70–90. http://dx.doi.org/10.1080/02643290802618757

Pylkkänen, L., & Okano, K. (2010). The nature of abstract orthographic codes: Evidence from masked priming and magnetoencephalography. *PLoS One, 5*(5), e10793. http://dx.doi.org/10.1371/journal.pone.0010793

R Core Team. (2015). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from http://www.R-project.org/

Vergara-Martínez, M., Gómez, P., Jiménez, M., & Perea, M. (2015). Lexical enhancement during prime-target integration: ERP evidence from matched-case identity priming. *Cognitive, Affective & Behavioral Neuroscience, 15,* 492–504. http://dx.doi.org/10.3758/s13415-014-0330-7

Vergara-Martínez, M., Perea, M., Marín, A., & Carreiras, M. (2011). The processing of consonants and vowels during letter identity and letter position assignment in visual-word recognition: An ERP study. *Brain and Language, 118,* 105–117. http://dx.doi.org/10.1016/j.bandl.2010.09.006

Received July 26, 2016
Revision received October 13, 2016
Accepted October 14, 2016 ■