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RESEARCH REPORT

Allograph Priming Is Based on Abstract Letter Identities: Evidence From Japanese Kana

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It is well-established that allographs like the uppercase and lowercase forms of the Roman alphabet (e.g., a and A) map onto the same "abstract letter identity," orthographic representations that are independent of the visual form. Consistent with this, in the allograph match task ("Are 'a' and 'A' the same letter?"), priming by a masked letter prime is equally robust for visually dissimilar prime-target pairs (e.g., d and D) and similar pairs (e.g., c and C). However, in principle this pattern of priming is also consistent with the possibility that allograph priming is purely phonological, based on the letter name. Because different allographic forms of the same letter, by definition, share a letter name, it is impossible to rule out this possibility a priori. In the present study, we investigated the influence of shared letter names by taking advantage of the fact that Japanese is written in two distinct writing systems, syllabic kana—that has two parallel forms, hiragana and katakana—and logographic kanji. Using the allograph match task, we tested whether a kanji prime with the same pronunciation as the target kana (e.g., 胃- い, both pronounced /i/) produces the same amount of priming as a kana prime in the opposite kana form (e.g., イ- い). We found that the kana primes produced substantially greater priming than the phonologically identical kanji prime, which we take as evidence that allograph priming is based on abstract kana identity, not purely phonology.

Keywords: abstract letter identities, Japanese kana, masked priming same-different match task, visual word recognition

Letters are visual objects, but they are more accurately "orthographic objects," which involve processing that is abstract with regards to their specific visual form. This property is apparent from the fact that literate individuals can readily recognize letters as identical despite variation in size, font, and allographic variation such as case (e.g., g, g, G). Many of the world's writing systems have allographic variations. For example, the Roman (as well as Greek and Cyrillic) alphabet contains upper- and lower-case forms of each letter identity, many of which are visually dissimilar (e.g., g/G, a/A). The Arabic alphabet does not have upper and lowercase forms, but has an extensive system of position-dependent allography: Depending on whether the letter occurs in the initial, medial or final position of a word, a letter can take up to four different visual forms. The Japanese kana syllabary has two parallel forms, hiragana and katakana.

Considering the Roman alphabet, there is extensive evidence that the upper- and lowercase form of letters map onto a single "abstract letter identity," an orthographic representation invariant to the visual form. This claim is well-supported, by neuropsychological data from impaired readers (Coltheart, 1981; Rynard & Besner, 1987), neural data (Dehaene et al., 2004; Polk & Farah, 2002; Rothlein & Rapp, 2014), and behavioral data from skilled adult readers (Besner, Coltheart, & Davelaar, 1984; Bigsby, 1988; Bowers, Vigliocco, & Haan, 1998; Kinoshita & Kaplan, 2008). The cross-case match task (also referred to as the nominal identity match task, e.g., Posner & Mitchell, 1967) is a tool used in many of these studies, and involves (simultaneous or sequential) presentation of letter pairs (e.g., a and A). Participants decide whether the letters presented are the same or different letter identity, ignoring letter case.

In recent years the cross-case letter match task has been supplemented with the masked priming cross-case letter match task (e.g., Kinoshita & Kaplan, 2008; Norris & Kinoshita, 2008), which

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is a sequential letter match task with the addition of a prime letter presented briefly before the target. When the prime has the same identity as the target (e.g., a - A), it facilitates the "*Same*" response, relative to a control prime with a different identity (e.g., x - A). Visual similarity of the prime-target pair can be manipulated, allowing for an examination of whether priming reflects abstract letter identities, or if it is instead sensitive to the visual appearance of letters. Studies conducting this manipulation have found equally robust priming for visually dissimilar cross-case prime-target pairs (e.g., g/G, a/A) and visually similar cross-case pairs (e.g., c/C, x/X), suggesting that it is not based on visual codes, and is instead based on abstract letter identities (Kinoshita & Kaplan, 2008; Norris & Kinoshita, 2008).

Using this task, evidence is beginning to emerge for abstract letter identities in writing systems other than the Roman alphabet. For example, Carreiras, Perea, and Abu Mallouh (2012) found robust cross-allograph priming for Arabic, which did not depend on the visual similarity between the forms. Schubert, Gawthrop, and Kinoshita (2017) tested adult L2 learners of Japanese, and found robust cross-kana (hiragana vs. katakana) priming, equivalent in size for visually similar and dissimilar kana prime-target pairs. These results suggest that "abstract letter identities may be universal" (the title of the Carreiras et al., 2012 article) across writing systems that have multiple allographs for a single letter identity.

Phonological Priming or Priming of Abstract Letter Identities?

One perennial question that arises from the pattern of priming observed with allograph primes is whether the effect could be based on shared phonology (letter name) rather than orthography (abstract letter identity). Although early studies (e.g., Posner & Mitchell, 1967) assumed that such cross-case matches are based on a phonological "name code," subsequent studies have conclusively argued against this assumption. Specifically, multiple studies have shown that the "*Different*" responses are unaffected by phonological similarity of letter names (e.g., Bigsby, 1988; Boles & Eveland, 1983; Carrasco, Kinchla, & Figueroa, 1988). Accordingly, it is generally accepted that cross-case matches are based on a "nonphonological, case-independent, font-independent, abstract representation" (cf. Bigsby, 1988, p. 455).

Despite this conclusion, the role of phonological codes in the match task continues to be raised as a possibility.[1] This line of query has precedence in the domain of word recognition. In discussing the equivalent cross-case word priming effect for visually similar prime-target word pairs (e.g., kiss/KISS) and dissimilar pairs (e.g., read/READ) reported by Humphreys, Evett, and Quinlan (1990); Lukatela and Turvey (1994) posited that "A better hypothesis, [. . .] is that variants of a letter in English are functionally equivalent because they map to an invariant configuration of phonological features" (p. 347), that is, cross-case word priming may be mediated entirely by phonological codes.

With words as stimuli, these possibilities can be distinguished by testing whether a homophonic prime produces the same amount of priming as a cross-case identity prime. Kinoshita and Norris (2009, Experiment 3) conducted such an experiment using the cross-case word match task. The identity prime (e.g., score-SCORE) produced 26 ms more facilitation than the pseudohomophone prime (e.g., skore-SCORE) but the latter did not produce any more priming (2 ms) relative to an orthographic control prime (e.g., smore-SCORE). Using a different set of words, Kinoshita, Gayed, and Norris (2017) replicated this pattern of results exactly, and additionally quantified the relative amount of evidence using the Bayes factor (see Morey & Rouder, 2015) that indicated an overwhelming amount of evidence that the cross-case identity priming effect is greater than the phonological priming effect.

With single Roman alphabet letters as stimuli, however, it is not possible to use the same manipulation. By definition, different allographic forms of a letter (e.g., b and B) have the same letter name ("bee"), and, different letter identities (e.g., a and b) have different letter names. There is no such thing as homophonic heterograph letters that can be used to test if allograph priming is phonological. This is also true of other orthographies with allographic variations like Greek, Cyrillic, and Arabic. However, because of its unique multiscriptal nature, in Japanese, it is not difficult to find homophonic heterographs that are not allographs.

Japanese Writing System

Japanese is unique in that it is written using two very different writing systems: logographic kanji and syllabic kana. Japanese kanji were adopted from Chinese hanzi, where each character is a morpheme. Kanji is used to write content words such as nouns (e.g., 胃, /i/, 'stomach'; 卵, /tamago/, 'egg') and stems of adjectives and verbs (e.g., 暗い/kura.i/'dark' or 歩く/aru.ku/'to walk'). All Japanese children are taught a predetermined number of kanji within each school year, totaling 1,006 kanji by the end of 6 years of primary school. The remaining 1,130 official (jōyō) kanji, prescribed by the Japanese Ministry of Education (see Tamaoka, Makioka, Sanders, & Verdonschot, 2017), are learnt during secondary education and students will have mastered 2,136 kanji upon completion, though most Japanese will know more kanji beyond this set (e.g., 狐 /kitsune/ 'fox,' known to many Japanese, is not in the jōyō kanji list).

Unlike kanji, kana is a syllabary and each of the 46 basic kana script maps one-to-one onto a mora, a syllable-like phonological unit comprised of either a single vowel or a consonant-vowel combination. (Unlike the Roman alphabet, there is no distinction between 'letter names' [e.g., "dee" for d/D] and 'letter sounds' [/d/]- the mora serves as both.) For each mora, there is a hiragana form and katakana form. For example, い and イ are the hiragana and katakana characters, respectively, for the mora /i/. Kana was derived in the 8th century from a set of Chinese hanzi characters introduced from China for their phonetic value. Japanese children are formally taught kana in the first year of primary school, and most acquire the whole set of kana by the end of first year; though, in practice, many children already know (some) kana before starting school.

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[1] Recently Lupker, Nakayama, and Perea (2015) reported that Japanese-English bilinguals asked to match English words (e.g., south/SOUTH) showed facilitation from masked primes which were a transliteration in Japanese katakana (e.g., サウス /sa.u.su/), that is, a phonological priming effect. However, their finding does not speak to the issue of whether priming produced by allograph letter primes is phonological because a word prime written in katakana obviously has no orthographic overlap with the target written in the Roman alphabet.

Hiragana and katakana are analogous to the upper- and lowercase forms in the Roman alphabet: Two parallel forms that correspond to the same identity, have the same letter name, yet can vary in their visual similarity. Both kana and the alphabet systems consist of a limited number of letters, and there is a recognized fixed "alphabetical" order of letters. Like the upper- and lowercase letters of an alphabet, hiragana and katakana letters are treated identically when the letters are sorted in order. The equivalent of alphabetical order in the kana system is the a-i-u-e-o order (also called the "Goju-on," meaning "fifty sounds," order), and for instance, personal names are sorted according to this order. These characteristics of the kana system suggest that hiragana and katakana letters are allographs, just like the upper- and lowercase forms of the Roman alphabet. Consistent with this, Japanese readers have no difficulty with the instruction to decide whether hiragana and katakana forms (e.g., い and イ, both representing the mora /i/) are the "same letter" ignoring the difference in form, just as alphabetic readers can apply the instruction to the upper- and lowercase forms of the Roman alphabet (Schubert et al., 2017). In contrast, a kanji character with a single-mora pronunciation could never be considered "the same letter" as the kana letter for that mora. Based on these features, we argue that hiragana and katakana forms are allographs that map onto a single abstract letter identity. In contrast, the logographic kanji is a distinct writing system from the kana system, and a kanji character which has the same pronunciation as a kana letter (e.g., 胃, pronounced /i/) is not an allograph, but a homophonic heterograph.

We did not expect the claim that the two kana scripts are allographic to be controversial, however, others seem to hold a differing view. This view seems to stem from the fact that hiragana and katakana are used to write different types of words. Hiragana is used to write grammatical markers, such as inflections and particles, as well as native Japanese words for which kanji are rare or unfamiliar (e.g., りんご /ringo/ 'apple'). Katakana is typically used to write foreign- or loan words (e.g., ドレス /doresu/ 'dress') and when using scientific or technical vocabulary (e.g., カワセミ /kawasemi/ 'kingfisher,' in biology). Although in principle any spoken word or nonword can be written in hiragana or katakana, foreign words and loan words are almost always written in katakana, and rarely appear in hiragana in text (i.e., "have zero frequency", cf. Pylkkänen & Okano, 2010). Based on this differential distribution of the kana scripts by word type, Pylkkänen and Okano (2010) assumed (wrongly, in our view) that hiragana and katakana belong to "different writing systems" (p.1), while Perea, Nakayama, and Lupker (2017) posited that "[..] these precise rules[2] of usage may hinder/prevent the development of abstract character-level representations" (p.1141). We will return to these studies in the Discussion, but for now, we point out that the use of hiragana and katakana to write different types of words does not provide a *prima facie* argument against a common abstract letter identity. The separate use of hiragana and katakana occurs at the word level, and not at the level of a single letter. Japanese readers would find a loanword written in hiragana (e.g., どれす, /doresu/ 'dress') to be orthographically unusual, just as an English reader would find an acronym written in lowercase letters (e.g., fbi, imf) to be orthographically unusual. Studies have shown that this orthographic unfamiliarity influences, but does not prevent, lexical access in the Roman alphabet (generally agreed to have abstract letter identities). For example, proper names (e.g., Anna, America) are recognized faster in initial-capitalized form (Peressotti, Cubelli, & Job, 2003), and recently Perea, Marcet, and Vergara-Marti′nez (2017) reported that while common nouns are recognized faster in lowercase than uppercase (e.g., molecule < MOLECULE), common nouns that are more often seen in capitalized form in signs and billboards (e.g., STOP, PHARMACY) are recognized equally quickly in uppercase and lowercase. The researchers (see also Perea, Rosa, & Marcet, 2017) took these findings to suggest that the orthographic format in which a word is presented is used as a cue in lexical access (the "orthographic cue hypothesis"), but importantly did not consider this to be evidence against abstract letter identities.

Experiment

In the present study, we took advantage of the presence of kanji and two kana forms to interrogate abstract identity priming in kana. Native Japanese readers completed a masked priming cross-kana match task, in which the reference and target were a single kana letter presented in the opposite format (hiragana vs. katakana, e.g., referent – い, target – イ, [mora /i/]), and the target was preceded by a briefly presented prime. The prime was either an identity prime or a control prime. The critical manipulation was the prime script (kanji or kana) within the identity primes. For both kana and kanji identity primes, the prime and target shared a pronunciation (e.g., kanji prime –胃, kana prime – い, target イ [mora: /i/]). On the assumption that allograph priming is purely phonological, the prediction is that the kanji prime would show the same size priming as the kana prime. However, if allograph priming is based on abstract kana identities, the priming produced by kanji primes should be smaller than that produced by the kana primes in the opposite format.

Method

Participants. Twenty-four students (average age = 20.67 ± 1.6 years, nine women) from Waseda University, Tokyo, Japan participated in the experiment. All were native speakers and native readers of Japanese, and had normal or corrected-to-normal vision.

Design. The experiment used a kana match task, and manipulated: (a) prime type (identity vs. control), and (b) prime script (kanji vs. kana). The dependent variables were response latency and error rate.

Stimuli. The critical stimuli were 16 kanji characters that had a single mora pronunciation (e.g., 胃, /i/, 'stomach'; 蚊, /ka/, 'mosquito') and 16 kana (hiragana and katakana) that had the same pronunciation as the kanji characters. As most kanji characters in Japanese have multiple pronunciations (cf. Verdonschot et al., 2013), care was taken to choose those with as few pronunciations as possible and with a single dominant pronunciation when presented as a single character. Where there were multiple kanji characters to choose from, those with fewer number of strokes

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[2] "Precise rules" is too strong. Some words can be written both in hiragana or katakana (e.g., りんご, リンゴ /ringo/ 'apple'). Moreover, even loanwords that are typically written in katakana may be written in hiragana or even in kanji as they become integrated into the Japanese language (e.g., テンプラ -> 天ぷら, "tempura", which was introduced by the Portuguese in the 16th century).

were chosen to keep the visual complexity low and, thus, more similar to the kana.[3] The mean frequency of the kanji characters was 173,576 (*SD* 210,169, range 1,202 to 593,691) according to an online Kanji Database (Tamaoka et al., 2017) that is based on the Mainichi Shimbun Newspaper corpus from 2000 to 2010, with a total of 282,816,611 morphological unit tokens (368,841 types) excluding proper nouns. The mean number of strokes for the kanji characters was 7.38 (*SD* 3.05, range 3 to 12). The list of stimuli is shown in the Appendix.

The task was a masked priming cross-kana match task. Each trial involved a referent, prime, and target, presented in that order. The referent and the target were always kana in the opposite kana format (hiragana or katakana), and on half of the trials the referent was hiragana and on the other half it was katakana. The prime was either a kanji or kana. Thus, for each target kana, the identity prime condition had four referent-prime-target combinations (see Table 1). When the prime was a kana, as is standard in the masked priming procedure, the prime and target kana were in the opposite format, thus for both kanji and kana identity prime conditions, there was little visual similarity between the prime and the target. For the *Different* condition, a referent kana different from the target was paired with the same prime-target pairs from the *Same* response condition (see Table 1).

Each trial began with the presentation of a reference kana, shown directly above a forward mask (###). After 750 ms, the forward mask was replaced by the prime for 50 ms, followed by the target letter, which remained until the participant responded or 2,000 ms elapsed. A blank screen (800 ms) intervened between trials. Stimuli were presented in black in the center of a white screen, in 12-point Hiragino Maru Gothic font. The target was magnified 1.2 times (this is done to avoid physical overlap between the target and an "identity" prime; however, in the present experiment this was not strictly necessary as none of the identity primes were physically identical). DMDX was used for the presentation of the stimuli and collection of responses (Forster & Forster, 2003).

Participants were instructed to decide, as quickly and accurately as possible, whether the two kanas presented in succession (the referent and target) were the same or different identity, ignoring the difference in format. (Participants had no difficulty understanding this instruction.) There was no mention of the presence of the primes. The experiment contained 256 trials per participant (2 [Response type: same/different] × 2 [Prime type: identity/control] × 2 [Prime script: kanji/kana] × 2 [referent kana type: hiragana or katakana] × 16 characters per condition). Participants first completed 16 practice trials involving characters that were not the critical stimuli. The order of trials within each experiment was randomized. Feedback was given only when an error was made.

Results

Reaction time (RT) for the correct trials and error rate were analyzed using mixed effects modeling, treating subjects and stimuli as crossed random effect factors. RTs were inverse transformed to best meet the distributional assumption of the model, and multiplied by −1,000 to maintain the direction of effects and reduce the number of decimal points (i.e., −1000/RT). A cutoff for outliers was determined by inspecting the Q-Q plots of inverse-transformed RT, no outliers were identified with this method. Analysis of error rates used a logistic link function. We used the *Lme4* package (Version 1.1–5; Bates, Maechler, Bolker, & Walker, 2014), implemented in R Version 3.0.3 (R Core Team, 2016). Degrees of freedom (Satterthwaite's approximation) and *p* values were estimated using the *lmerTest* package (Version 2.0–11; Kuznetsova, Brockhoff, & Christensen, 2016). In line with the recommendation to keep the random effect structure maximal (Barr, Levy, Scheepers, & Tily, 2013), the initial model included random slopes on participants and stimuli; the final model we report was selected using a backward stepwise model selection procedure. We also computed Bayes Factors (BF) using the *BayesFactor* R package (Morey & Rouder, 2015). A BF indexes the proportion of evidence for one hypothesis over another and was used to supplement null-hypothesis significance testing. The typical value considered to be reliable evidence for a hypothesis is a BF >3 (Dienes, 2014; Jeffreys, 1961).

We analyzed only the *Same* responses, where masked priming effects are observed in the same-different task (Norris & Kinoshita, 2008). The factor prime type (Identity or Control) was deviation-contrast-coded (−.5, .5), and the prime script factor was referenced to the kana condition.

The RT and error data are presented in Table 2. In the analysis of correct RT for the *Same* trials, there were 2,965 data points. The best fitting statistical model was: invRT ∼ prime script ∗ prime type + (1 | target) + (1 + primetype | subject). The main effect of prime type was significant, $t = -10.410$, $p < .001$. The main effect of prime script was nonsignificant, $t = 0.853$, $p = .394$. Critically, these two factors interacted, $t = 6.021$, $p < .001$.[4] As is apparent from Table 2, priming was substantially larger for the kana primes (46 ms) than for the kanji primes (17 ms). The Bayes Factor was 2,514,424 in favor of the presence of this interaction, indicating exceedingly strong evidence for the modulation of priming by the prime script.

In the analysis of errors, the final statistical model was: error ∼ prime script ∗ prime type + (1 | target) + (1 | subject). The main effect of prime type was significant, $Z = -5.185$, $p < .001$, as was the main effect of prime script, $Z = -2.862$, $p < .01$. The interaction was nonsignificant, $Z = .992$, $p = .32$. Table 2 shows that these effects reflect that there were more errors when the prime was a control prime relative to an identity prime, and when the prime was a kana rather than a kanji.

In this experiment, the visual similarity of the cross-kana pairs was not specifically manipulated (the choice of the kana stimuli

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[3] Kanji characters are generally more visually complex than kana, and hence a difference in visual complexity is unavoidable. Note, however, that while visual complexity tends to slow down letter match for naïve readers unfamiliar with the orthography, its effect tends to be facilitatory for expert readers (like our participants), "perhaps because they (visually complex letters) are more distinctive" (Wiley, Wilson, & Rapp, 2016, p. 1201). The difference in visual complexity, therefore, cannot explain a smaller priming effect with the kanji primes relative to the kana prime in the present experiment.

[4] Balota, Aschenbrenner, and Yap (2013) pointed out that because the inverse transformation reduces differences at slower RTs, when RTs are inverse-transformed to meet the distributional assumptions of LME (an overadditive interaction may fail to be detected or), a spurious underadditive interaction may be introduced. The form of interaction observed here is a cross-over interaction and, thus, cannot be an artefact of the inverse transformation.

Table 1
Example Stimuli from the Kana Match Task

Response type	Prime script	Prime type: Identity	Prime type: Control
Same	Kanji	イ-胃-い, い-胃-イ	イ-戸-い, い-戸-イ
	Kana	イ-イ-い, い-い-イ	イ-ト-い, い-と-イ
	Pronunciation	/i/ - /i/ - /i/	/i/ - /to/ - /i/
Different	Kanji	ナ-胃-い, な-胃-イ	ナ-戸-い, な-戸-イ
	Kana	ナ-イ-い, な-い-イ	ナ-ト-い, な-と-イ
	Pronunciation	/na/ - /i/ -/i/	/na/ - /to/ - /i/

Note. The stimuli are shown in the order referent—prime—target. "Same/Different" refers to whether the referent and target had the same abstract kana identity. "Identity/control" refers to (phonological) identity of the prime and target. All referent-target pairs contained a hiragana and katakana pair in opposite format, with the referent in katakana (and the target in hiragana) on half of the trials and the referent in hiragana (and the target in katakana) on the other half.

was determined by the availability of homophonic kanji character), and while most of the pairs used were visually dissimilar (see Appendix), a couple of the kana pairs were visually similar (e.g., り/リ, か/カ). To confirm that allograph priming is independent of visual similarity, we calculated the correlation between the size of the cross-kana priming effect (averaged over the 24 subjects) for the 16 kana pairs and the rated visual similarity of the kana pairs obtained in a previous study (Schubert et al., 2017) as listed in the Appendix. The mean priming effect was 47 ms (*SD* 23) and the mean similarity rating (on a scale of 1 to 5, with 1 = *not at all similar*; 5 = *very similar*) was 2.4 (*SD* 1.29). The correlation between these was nonsignificant (r = .18, p = .506).[5]

Discussion

We examined whether allograph priming in the cross-kana match task reflects abstract kana identities or phonology by comparing priming produced by cross-kana identity primes (e.g., イ- い) and kanji primes that have the same pronunciation (e.g., 胃 - い, both pronounced /i/ - /i/). The result was straightforward: although the homophonic kanji primes produced priming, it was substantially smaller (17 ms) compared with the effect produced by the cross-kana identity prime (46 ms), indicating that allograph priming is not mediated solely by phonology. The size of cross-kana identity priming effect was also uncorrelated with the visual similarity of the kana pairs. We take these results as evidence that allograph priming is based on abstract letter identity. This is the first demonstration that allograph priming is distinct from phonological priming; this was made possible by the fact that Japanese is written using logographic kanji, as well as syllabic kana with two parallel forms, hiragana and katakana.

Table 2
Mean Decision Latencies and Error Rates for the Kana Match Task

Response type and Prime script	Identity RT (*SD*)	Identity %E	Control RT (*SD*)	Control %E	Priming effect RT	Priming effect %E
Same						
Kanji	424 (67)	1.2	441 (68)	3.3	17	2.1
Kana	411 (69)	1.8	457 (67)	7.7	46	5.9
Different						
Kanji	469 (64)	2.0	476 (69)	1.8		
Kana	460 (75)	1.7	455 (66)	1.3		

Note. *SD*s are presented in parentheses; %E = the percentage of error rates. Priming effect is the difference between the Identity and Control conditions.

There are two previous studies that used cross-kana primes and they came to a conclusion that is different from the present study, as well as from each other. Both studies used words that are normally written in katakana that is, loan words, as targets in a lexical-decision task. Pylkkänen and Okano (2010) reported finding statistically equivalent masked priming effects for the cross-kana identity prime (e.g., ぴーまん -ピーマン, "pepper") and the same-kana identity prime (e.g., ピーマン -ピーマン). From this, they concluded that for hiragana and katakana "sound identity is what determines orthographic identity: as long as the symbols express the same sound, our minds represent them as part of the same character/letter" (p.1, Abstract). As discussed in the Introduction, cross-kana priming effect (with single letters or words as stimuli) with visually dissimilar primes in of itself is equally interpretable in terms of abstract letter identities or phonological codes—indeed, this is what motivated the present study—and there is nothing in their data that rules out the former.

Also using the masked priming lexical-decision task, Perea, Nakayama, and Lupker (2017) came to a very different conclusion from Pylkkänen and Okano (2010), that "in Japanese, abstract units are shared at the lexical level, but not at the character level" (p. 1144). In their study, the identity primes containing alternating

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[5] Additionally, the LME model (invRT ~ prime script * prime type + (1 | target) + (1 + primetype | subject) excluding the 4 hiragana-katakana pairs that had the above-average visual similarity ratings (り/リ, か/カ, き/キ, こ/コ) produced the same pattern of effects as the full set. More important, the prime type * prime script interaction was significant, t = 4.41, p < .001, with a Bayes factor of 740, indicating that the priming effect remains greater for visually dissimilar kana primes (44 ms) than for kanji primes (18 ms).

hiragana and katakana (e.g., レすトらン- レストラン, "restaurant") produced priming which was smaller (17 ms) than the identity prime containing all katakana (28 ms, e.g., レストラン - レストラン). As we noted earlier in the article, when words are used as stimuli, the observed effect of orthographic format could be on the ease of lexical access. Perea, Nakayama, and Lupker (2017) ruled out this interpretation out of consideration at the outset, on the grounds that their study manipulated the orthographic format of the *masked primes* (not the visible targets like the studies we described earlier in the article), and on the assumption that the information about the specific visual form of the letters is "lost early in processing" (Perea, Nakayama, and Lupker, 2017, p. 1141). Indeed, on this assumption, the familiarity of the orthographic format of the masked primes would not be expected to affect the size of priming. However, there is evidence that orthographic format of masked primes is not lost: Perea, Jiménez, Talero, and López-Cañada (2015) reported that for brand names which are written in a specific format (e.g., adidas, IKEA), priming is reduced when the masked identity prime was in the unfamiliar format (ADIDAS - adidas) than in a familiar format (e.g., adidas - adidas).[6] Thus, the reduced priming with the alternating kana identity prime observed by Perea, Nakayama, and Lupker (2017) is similarly interpretable in terms of the effect of unfamiliar orthographic format on the ease of lexical access.

On this interpretation, what needs to be explained is why Pylkkänen and Okano (2010) did not find an effect of orthographic format familiarity: Their cross-kana identity primes written in hiragana (e.g., ぴーまん) were also orthographically unfamiliar, and would, therefore, be expected to reduce priming like Perea, Nakayama, and Lupker's (2017) alternating kana primes. We believe the null difference is likely because of low statistical power: Pylkkänen and Okano's (2010) experiment tested only eight participants compared with Perea, Nakayama, and Lupker's (2017) 48. The lexical decision latencies in Pylkkänen and Okano's (2010) experiment were also unusually slow, with the fastest identity prime condition being well over 700 ms compared with Perea, Nakayama, and Lupker's (2017) data of around 520 ms. These aspects of the data suggest that Pylkkänen and Okano's (2010) failure to find a reduced priming effect with the hiragana primes relative to the katakana primes may have been a Type-II error, and the empirical discrepancy between the two studies may be more apparent than real. It should also be borne in mind that with words normally written in lowercase in the Roman alphabet, whether the mIxEd cAsE primes produce a smaller identity priming effect than the UPPERCASE primes has not been tested directly within an experiment using the same target words; similarly, whether alternating-kana primes produces a smaller priming than the hiragana primes for the recognition of Japanese loanwords should be investigated in future. The main take-home message is that researchers need to consider the role of orthographic format familiarity when using word stimuli before drawing conclusions about the nature of letter representations (see Bowers et al., 1998, for discussion of the "letter-word equivalence assumption" held implicitly by many researchers).

In conclusion, the present study is the first study that used single letter stimuli and showed that allograph priming is based on abstract letter identities, not phonology. Our experimental design capitalized on the unique nature of Japanese writing systems, and along the way we also pointed out commonly held misconceptions about Japanese hiragana and katakana. We hope our study paves the way for a better understanding of the language-specific and universal aspects of letter and word processing.

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[6] To be more precise, it was only the brand names that are written in lowercase (e.g., adidas) that showed reduced priming with orthographically unfamiliar uppercase prime; brand names that are written in uppercase (e.g., IKEA) were primed equally by uppercase and lowercase primes. The interaction between the familiarity of letter case (lowercase letters are more frequent in normal text) and orthographic format needs further investigation.

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(*Appendix follows*)

Appendix

List of Stimuli Used

Target	Kana identity prime	Cross-kana similarity rating	kanji identity prime	Roman transcription of referent and identity prime	Kana control prime	Kanji control prime	Roman transcription of control prime
い	イ	1.8	胃	i	ト	戸	to
え	エ	2.4	絵	e	チ	血	chi
か	カ	5	蚊	ka	イ	胃	i
き	キ	4.6	木	ki	ナ	名	na
こ	コ	3.4	子	ko	エ	絵	e
し	シ	1	死	shi	カ	蚊	ka
す	ス	1.2	巣	su	キ	木	ki
た	タ	1.4	田	ta	シ	死	shi
ち	チ	1.6	血	chi	ワ	和	wa
と	ト	2	戸	to	メ	目	me
な	ナ	2.4	名	na	ホ	帆	ho
ほ	ホ	1.6	帆	ho	リ	理	ri
ま	マ	1.6	間	ma	ス	巣	su
め	メ	1.4	目	me	タ	田	ta
わ	ワ	2.4	和	wa	コ	子	ko
り	リ	4.6	理	ri	マ	間	ma

Note. The list depicts the condition in which the target was in hiragana; on half of the trials they were presented in katakana. Note that the referent and the target were always presented in the opposite kana format (hiragana vs. katakana). The cross-kana similarity rating (scale 1–5, with 1 = *being not at all similar* and 5 = *being very similar*) was collected in a previous study (Schubert et al., 2017) from five native Japanese readers.

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