

An investigation into the structure and acquisition of orthographic knowledge:  
Evidence from cross-script Kanji-Hiragana priming.

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### Abstract

Numerous studies have demonstrated that orthographic knowledge is coded in an abstract format in English (e.g., the perceptually dissimilar words READ/read map onto a common abstract orthographic representation). However, it is unclear at present whether this mapping occurs at the letter or word level. Two experiments investigate this issue in a language (i.e., Japanese) where words can be written in perceptually unrelated scripts (Kanji and Hiragana), and crucially, where there are no letter correspondences between scripts. Using the long-term priming paradigm, robust priming was obtained when study/test words were depicted in Hiragana/Kanji, and vice versa. Furthermore, little priming was obtained following a study/test modality shift. The modality specific nature of this priming suggests that corresponding words in the two scripts share common orthographic representations. A model is out-lined that describes how abstract orthographic knowledge is acquired.

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A central issue for theories of reading concerns how letters and words are represented orthographically. That is, how written materials are perceptually coded within the visual system. According to most accounts, orthographic knowledge is coded in an abstract format such that different exemplars of a given stimulus map onto the same representation (e.g., Coltheart, 1981; McClelland, 1976). For example, the visual patterns A/a or READ/read are thought to map onto common orthographic codes, despite the perceptual dissimilarity of the items. This is assumed to be the case even for items that are arbitrarily related in their perceptual form, as in the examples above.

Evidence for the existence of abstract orthographic codes comes from a variety of sources. Coltheart (1981), for example, describes a conduction aphasic patient who could not name pseudowords (e.g., nega), but who nevertheless was able to match upper/lower pseudowords that were perceptually dissimilar (e.g., NEGA/nega) without difficulty. Given that these items are (a) meaningless, (b) perceptually dissimilar in upper/lower case, and (c) unpronounceable by the patient, Coltheart concluded that the patient accessed abstract orthographic codes in order to perform the task. Consistent with this conclusion, McClelland (1976) reported that the word superiority effect (WSE) is equally large for words presented in case uniform and mixed conditions; for example the words FADE and fAdE were both better identified than the matched pseudowords GADE and gAdE in a task in which participants attempted to identify briefly presented targets. Given that mixed-case words are unfamiliar visual patterns, these results suggest that the WSE is mediated by word representations coded in an abstract fashion (also see Bowers, Bub, & Arguin, 1996). In addition, Bowers (1996) found long-term priming to be equally robust for words repeated in the same and different case, even though the different-case words were perceptually dissimilar at study and test (e.g., READ/read). This cross-case priming was attributed to orthographic knowledge, since the priming was dramatically reduced following a study/test modality shift in which words were studied auditorily and tested visually (for additional evidence in support the existence of abstract orthographic knowledge, see Besner, Coltheart, & Davelaar, 1984; Bowers, Arguin, & Bub, 1996; Evett & Humphreys, 1981; Rayner McConkie, & Zola, 1980, among others; but see Boles, 1992).

Taken together, these findings strongly support the conclusion that orthographic knowledge is coded abstractly. Under this assumption, two related questions need to be addressed, namely, (a) where within the orthographic system are these abstractions learned (i.e., the letter or word level), and (b) how are these codes acquired. Clearly, answering (a) greatly constrains the solutions to (b), and accordingly, it is first necessary to determine the specific loci at which abstractions takes place. One possibility is that learning selectively occurs at the letter level, which would lead to abstract word codes, but only in virtue of letters serving as input to word representations. Alternatively, some learning procedure may operate at multiple levels, and accordingly, the existence of abstract word knowledge would not be contingent on, nor necessarily the product of, abstract letter codes.

Current findings suggest that, at minimum, a learning process acts directly on letter representations to create abstract letter codes. Perhaps the best evidence in support of this conclusion is that the word superiority effect extends to words presented in mixed case letters (McClelland, 1976). Mixed-case words are unfamiliar (and unrecognizable) when considered as complete visual patterns, and the only familiar (and recognizable) features of the words are the component letters themselves. Thus, the WSE must reflect the activation of abstract letter codes, which in turn leads to the activation of abstract word codes (for additional evidence, see Besner & Jolicoeur, submitted; Rynard & Besner, 1987; for further discussion of this issue, see Bowers, Vigliocco, & Haan, in press).

However, these and related findings cannot be used to determine whether learning is restricted to the letter level. The reason, of course, is that upper- and lower-case words are composed of upper- and lower-case letters, and accordingly, any demonstration that words are coded abstractly can be attributed to learning that took place at the letter level. In order to avoid this ambiguity, it is necessary to determine the structure of word representations under a specific condition, namely, when: (a) words can be depicted in dissimilar formats, and (b) the different formats do not share letter-by-letter correspondences. If these types of words map onto common orthographic codes, then it must be concluded that the learning process interacts with word level knowledge (since common abstract letter codes do not exist for these items).

In fact, a study by Brown, Sharma and Kirsner (1984) provides some evidence compatible with this view. These authors assessed priming for Indian words displayed in Hindi/Urdu scripts: The spoken forms of these scripts are identical under normal circumstances, but their written forms are unrelated, and they do not share a simple letter-by-letter correspondence. Employing the lexical decision task, they observed similar (nonsignificantly different) amounts of priming when items were studied and tested in the same (113ms) and different (93 ms) script conditions, consistent with the conclusion that Hindi/Urdu words map onto common orthographic word representations. It is important to note, however, that the authors did not compare the size of cross-script priming (which can be attributed to orthographic, semantic or phonological codes) to cross-modal priming (which can be attributed to semantic or phonological codes), and accordingly, the relative contribution of modality specific (orthographic) and modality independent (non-orthographic) codes cannot be determined. In fact, Kirsner, Dunn, & Standen (1989) attribute this priming to phonological representations.

Two experiments are reported below that attempt to clarify this issue by comparing cross-script to cross-modal priming for words that do not share letter-by-letter correspondences in the two scripts; specifically, Kanji and Hiragana scripts of Japanese. Kanji characters (based on Chinese ideograms) represent morphemes, whereas Hiragana characters represent syllables, and the same set of words are depicted in both scripts. (Children tend to learn Hiragana first, and later Kanji.) In Experiment 1, test words were presented in Hiragana, and in Experiment 2, test words were presented in Kanji, providing an opportunity to assess cross-script priming in both the Hiragana-Kanji and Kanji-Hiragana study/test directions. See Figure 1 for a partial list of the experimental items used in Experiment 1. If robust cross-script priming is obtained in the face of minimal

cross-modal priming, then the priming would appear to be mediated by abstract orthographic word codes.<sup>1</sup> The two experiments are described together.

### Method

Participants. A group of 32 Native Japanese speakers from the Houston and Madison areas volunteered to participate in Experiment 1 in exchange for \$5.00, and another group of 32 Japanese speakers from the University of Ryukyus volunteered to participate in Experiment 2.

Design and Materials. Experiments 1-2 included study/test condition as a within-subject factor (study and test items presented in the same script vs. different scripts vs. different modalities vs. a nonstudied baseline condition). Different sets of Kanji-Hiragana word-pairs were used in the two experiments. In Experiment 1, the critical materials consisted of 64 common Kanji-Hiragana words and a set of 64 pronounceable Hiragana nonwords matched in length with the Hiragana words. In Experiment 2, the critical materials consisted of 64 common Kanji words composed of two Kanji characters (e.g., 音楽, meaning music), the corresponding set of Hiragana words, and nonwords composed of two Kanji characters combined in a meaningless way (e.g., カキ). These latter words were selected from a set of the 2,000 most basic words in Japanese (The National Language Research Institute, 1984). Homophones were excluded from both word-lists.

In the study phase of both Experiments, 16 Kanji, 16 Hiragana, and 16 spoken words were presented in a random order, and at test, all 64 words and 64 nonwords were visually presented in a random order. Four experimental files were created for each experiment so that each word was presented in each condition equally often, yielding counter-balanced designs.

Procedure. The procedure of the two experiments was similar. In the study phase, participants read aloud all written words, and repeated aloud all spoken words. Words were presented one at a time, every 4 seconds. Immediately after completing the study phase, participants completed a lexical decision task. A practice set of 10 words and 10 nonwords were initially presented, followed by the critical items. In Experiment 1, participants pressed the right shift key of a computer keyboard as quickly as possible when the item was a word, and the left shift key otherwise. In Experiment 2, they pressed the right button of a mouse key-pad if the item was a word, and the left button otherwise.

### Results

The lexical decision latencies and error rates in the various conditions of Experiments 1-2 are shown in Table 1. In Experiment 1, an analysis of the response latencies showed an effect of the study/test condition [ $F(3,93) = 7.79$ ,  $MSe = 969$ ,  $p < .01$ ], reflecting the robust priming in the repetition (31 ms) and cross-script (31 ms) conditions. Critically, a simple contrast revealed significantly more priming in the cross-script (31 ms) compared to the cross-modal (10 ms) condition [ $F(1,31) = 6.56$ ,  $MSe = 975$ ,  $p < .05$ ], indicating that the cross-script priming was, in large part, modality specific.

Indeed, the cross-modal priming was not significant [ $F(1,31) = 1.37$ ,  $MSe = 1237$ ,  $p > .25$ ]. The analysis of the error rates failed to reveal a main effect,  $F(3,93) < 1$ .<sup>2</sup>

Similar results were obtained in Experiment 2. An analysis of the response latencies showed a main effect of the study/test condition [ $F(3,93) = 11.13$ ,  $MSe = 386$ ,  $p < .01$ ], reflecting the robust priming in the repetition (25 ms) and cross-script (17 ms) conditions. A simple contrast revealed significantly more priming in the cross-script (17 ms) compared to the cross-modal (3 ms) condition [ $F(1,93) = 7.78$ ,  $MSe = 386$ ,  $p < .01$ ], and again, the cross-modal priming was not significant,  $F(1,93) < 1$ . The analysis of the error rates revealed an effect of condition [ $F(3,93) = 3.13$ ,  $MSe = .003$ ,  $p < .05$ ], reflecting the higher error rates in the baseline (.06) and cross-modal (.06) compared to the repetition (.03) and cross-script (.04) conditions.

## Discussion

The combination of robust cross-script and minimal (nonsignificant) cross-modal priming strongly suggests that corresponding Kanji and Hiragana words map onto common orthographic representations. These results extend the recent report of modality specific cross-case priming in English (e.g., READ/read; Bowers, 1996), and suggest that abstract orthographic word codes can be acquired independently of abstract letter codes.

It is worth contrasting these cross-script and cross-case priming results with the null effects obtained between translation equivalents in bilingual speakers (e.g., Durgunoglu, & Roediger, 1987; Kirsner, Smith, Lockhart, King, & Jain, 1984), and the small or null priming effects obtained between heterographic homophones (e.g., sale/sail; Neisser, 1954; Ziemer & Bowers, 1997). These latter results also demonstrate that semantic and phonological codes play a relatively small role in mediating long-term priming for visually presented test words, and thus provide further support for the conclusion that the cross-script and cross-case priming is mediated by orthographic codes.

These findings raise the interesting question as to how abstract orthographic codes are acquired in the first place. That is, how does a perceptual system map together letters and words that are unrelated in their perceptual structure? In the following pages, we begin to outline one possible theory.

How to acquire abstract letter and word codes. The Hiragana-Kanji priming results, in combination with findings supporting the existence of abstract letter codes (e.g., McClelland, 1976), suggest that the relevant learning processes directly interact with both letter and word codes during the development of abstract orthographic knowledge. Accordingly, learning is not restricted to a small set of letter codes, but instead extends to the much larger set of lexical-orthographic codes.

In considering the nature of this learning process, one conclusion seems necessary; namely, letter and word representations cannot be learned on the basis of the visual properties of the input. That is, bottom-up visual information cannot be used to map together arbitrarily related perceptual forms, such as the words . Instead, it is necessary to assume that a non-visual "teacher" acts on the orthographic

system in a top-down fashion in order to organize the perceptual representations of both letters and words.<sup>3</sup> This teacher would instruct the orthographic system to map together specific patterns (such as A/a) even though the items are perceptually unrelated.

One likely candidate for an external teacher is the phonological system, consistent with theories of reading that assume bi-directional connections between orthographic knowledge on the one hand, and phonological codes on the other (e.g., Grainger & Ferrand, 1994; Van Orden, Pennington, & Stone, 1990). To see how phonology could act as a teacher, consider two arbitrarily related visual letters (e.g., A/a), as depicted in Figure 2. In this figure, the two visual patterns map onto the same phonological representation, and because of the bi-directional connections between orthography and phonology, both orthographic patterns are consistently co-activated within the orthographic system, via feedback. It is this co-activation that makes it possible to learn arbitrary perceptual mappings. More specifically, the learning process might proceed as follows. When a child learns that visual pattern A maps to sound /ei/, a bi-directional connection develops such that the presentation of A leads to the activation of /ei/ and the presentation of /ei/ activates A. Similarly, when the child learns that the visual pattern a maps onto /ei/, bi-directional connections develop. As a result, when one of the visual patterns is presented, for example A, it activates /ei/, which in turn activates A and a, given the learned feedback connections (Note, it is irrelevant whether the child learns the names for A and a at the same time. Co-activation of the visual patterns would be robust in either case).

This co-activation, when combined with associative learning principles, provides a simple mechanism for acquiring abstract orthographic representations. For example, the Weber and Associative Decay rules described by Carpenter and Grossberg (1987; also see Bowers & Vigliocco, submitted) would serve to associate representations that are consistently co-activated within the orthographic system, such as the letters A/a. These learning principles can readily account for the development of abstract orthographic codes between Kanji and Hiragana words, given that these dissimilar scripts contact the same lexical-phonological codes, which in turn would result in the consistent co-activation of both visual patterns each time one word is presented, via feedback.

It is important to note that there is independent evidence that orthographic and phonological codes are bi-directionally connected. The connections from orthography to phonology are not in dispute as these connections form the primary basis for reading aloud in most models of reading. In addition, there is also strong evidence for connections from phonology to orthography. For example, Dijkstra, Oelofs, & Fieus (1995) reported that phoneme monitoring times for phonemes embedded in spoken words are affected by the spelling of the words, and Seidenberg and Tanenhaus (1979) reported that rhyme judgments of spoken words are more difficult when the words have dissimilar orthographies. For example, participants are faster to say that lie and tie rhyme compared to rye and tie. In both of the above examples, the orthographic properties of the materials are irrelevant to the task demands, and nevertheless these codes are contacted and affect performance. More recently, Stone, Vanhoy, & Van Orden (1997) reported that visual lexical decisions are not only affected by the consistency with which a word's orthographic structure maps onto phonology, but also by the consistency with which its phonological structure maps onto orthography, with slower lexical decisions obtained for words with

bi-directional inconsistencies. Taken together, these findings strongly support the conclusion that bi-directional connections exist between orthographic and phonological representations, and lend support to the hypothesis that phonological codes act as teacher in constructing abstract orthographic representations.

In the above example, phonological codes played the role of teacher, but it is also possible that bi-directional connections exist between orthographic and lexical-semantic representations, and these latter codes also contribute to the development of abstract orthographic representations. One finding compatible with this claim is that heterographic homophones (e.g., sail/sale) do not map onto common abstract orthographic codes (as demonstrated, among other findings, by the small or non-existent long-term priming obtained between heterographic homophones; Neisser, 1954; Ziemer & Bowers, 1997). One possibility is that although these items receive consistent feedback from common lexical-phonological codes, they do not receive consistent feedback from lexical-semantic codes, which prevents the development of abstract orthographic knowledge. So on this account, abstractions between perceptually unrelated words only take place when the orthographic system receives consistent feedback from both phonological and lexical-semantic codes.

Additional evidence compatible with the view that lexical-semantic codes assist in the role of teacher comes from studies that indicate that orthographic representations encode morphological relations, at least when the items are regularly related in their phonological form (e.g., guest/guests). Morphological relations are defined on semantic criterion, and it is often suggested that morphological relatives (at least inflections) share common lexical-semantic codes (e.g., Levelt, 1989). One possible explanation for the development of morphological structure within orthography is that different inflectionally related words receive feedback from common lexical-semantic codes, which in turn leads to the consistent co-activation of these orthographic patterns. Furthermore, if consistent feedback is required from both semantic and phonological codes, then it might be predicted that the orthographic system would not map together irregularly related items, such as goose/geese. Indeed, it has been argued that orthographic representations only encode regular relations (e.g., Caramazza, Laudanna, & Romani, 1988). So on the present argument, the same learning principles that account for the development of abstract cross-case and cross-script representations also explain the development of morphological structure within the orthographic system.

To summarize, according to the present hypothesis, semantic and phonological representations act together as teacher to support the learning abstract orthographic codes. Note, it is not being claimed that phonological or semantic information is represented internally to the orthographic system. Rather, these codes provide the feedback that results in the consistent co-activation of orthographic patterns (such as a/A), and then associative learning within the orthographic system maps these items together to form abstract orthographic codes.

Before concluding this discussion, two possible points of confusion should be addressed. First, the empirical finding that long-term priming is largely modality specific may appear to be at odds with the claim that bi-directional connections exist between

phonological and orthographic knowledge (and between semantic and orthographic knowledge). This theory might seem to predict robust cross-modal priming. However, theory and data can be reconciled if it is assumed that long-term priming is greatly reduced between associated as compared to repeated study/test items. Indeed, the empirical findings seem to require this assumption, not only to account for the reduction of cross-modal priming, but also to account for the small or non-existent long-term priming obtained between synonyms and written associates (e.g., elephant-tusk; Roediger & Challis, 1992). So on the present theory, complete priming is obtained between Kanji and Hiragana words because they gain repeated and direct access to the same orthographic representations. By contrast, reduced priming is obtained between spoken and written words (and semantic associates) because the study/test items only gain access to the same representations indirectly through association.

Second, the claim that different visual instances of letters and words are co-active each time a specific item is studied might seem to render the development of abstract orthographic codes superfluous. For example, if studying the lower-case word garden leads to the co-activation of the orthographic patterns garden and GARDEN, then these separate representations might individually support priming when garden or GARDEN is repeated at test. On this argument, then, priming would occur without positing abstract orthographic codes. However, this interpretation runs into trouble because it attempts to explain long-term priming on the basis of associative effects -- and as seen above, long-term associative priming tends to be much reduced in comparison to repetition priming. In addition, this characterization of orthographic knowledge runs into empirical difficulties in other domains. For example, as noted in the introduction, some aphasic patients cannot access to phonology from print, and nevertheless, they can match visually dissimilar upper- and lower-case letter strings that are meaningless (e.g., NEGA/nega; Coltheart, 1981). Given that phonology and semantics cannot support the co-activation of these orthographic patterns via feed-back, it is difficult to explain this result without positing abstract letter codes.<sup>4</sup>

Implications for modularity. On a closing note, it is worth mentioning the implications of the present finding for theories of modularity. One of the basic premises of modular theories of perception is that the representations internal to a given system are insulated from other types of information. For example, the perceptual processes involved in identifying the written word table are presumed to be unaffected by our background knowledge of meaning and phonology. However, the present finding suggests that orthographic representations are structured in such a way that they are compatible with our background knowledge (e.g., that Kanji/Hiragana words share the same meaning and the same name, and that car/cars are inflectionally related), even though this structure cannot be determined on the basis of the perceptual attributes of the words themselves. On the present argument, this structure is learned through a penetration of lexical-semantic and phonological information into the orthographic system, contrary to a modular view of word perception. Whether or not this specific characterization of the learning is correct, some type of top-down teacher seems required, and any such teacher violates the view that visual word recognition takes place within a modular system.

Perhaps an advocate of modular theories would object, and say that modularity is a theory of on-line perceptual processing, not a theory of perceptual learning. That is, it could be claimed that the learning processes themselves are non-modular, but once the various perceptual systems are setup, the identification of words (or whatever else) takes place in a modular fashion. Still, one is left with the dilemma of how a non modular learning procedure can operate in the context of a modular theory of on-line perceptual processing. The present characterization of word processing certainly does not fit this account, given that the learning was dependent upon semantic and phonological information consistently activating orthographic representations. Thus, a challenge for the modularist, it seems, is whether a motivated distinction can be drawn between non-modular learning and modular on-line perceptual processing. This is clearly an interesting question that merits further study.

## Footnotes

1. Komatsu & Naito (1992) assessed priming between Hiragana and Katakana words in Japanese, and reported that the cross-script priming was no larger than the cross-modal priming. It is important to note, however, that Katakana and Hiragana are used to represent foreign loan and common words respectively, and thus Japanese readers do not have any experience reading the same word in the two scripts. Accordingly, it is not surprising that abstract orthographic codes do not develop between these items. By contrast, Kanji and Hiragana scripts depict the same set of words, and thus abstract orthographic codes should develop between these scripts if learning takes place at the word level.
  
2. Although the error rates in the various conditions did not differ significantly from one another, there was a slight trend for more errors in the cross-script (3.3) compared to the cross-modal (1.9) condition, which might raise concerns that the greater RT priming in the cross-script (31 ms) compared to cross-modal (5 ms) condition was the product, at least in part, of a speed-accuracy tradeoff. In an attempt to evaluate this possibility, we removed from each of the 4 counter-balanced files the results of the participant who had the largest discrepancy in error rates in these two conditions, with more errors in the cross-script condition. By this criterion, we were able to unambiguously remove 1 participant from each file, and re-compute the error and RT data. Not surprisingly, after removing the results of these 4 participants, the error rates in these two conditions was similar, with slightly fewer errors in the cross-script (3.10%) compared to the cross-modal (3.77%) condition. Critically, the pattern of the RT data remained unchanged, with 27 ms priming in both the repetition and cross-script conditions, and 6 ms priming in the cross-modal condition, indicating that the RT priming results cannot be attributed to a speed accuracy trade-off.
  
3. Polk and Farah (in press) have advanced an account of how abstract letter codes might be acquired in a bottom-up account in English. Their argument is that most letters are visually similar in upper- and lower-case, and these items provide a context in which abstract codes can be acquired for visually dissimilar letters. So, although A/a cannot be mapped together in a bottom up fashion when considered in isolation, the items are learned in the context of words that are similar overall, such as CAP/cap. It is through the context of the similar letters that they suggest that abstract letter codes are acquired. They in fact describe a simple Hebbian learning model that does learn abstract letter identities through the use of similar letter contexts. However, this cannot be the complete story, since this approach cannot account for the development of orthographic codes that map together Kanji/Hiragana words. For these words, there are no similar contexts that could provide a basis for bootstrapping. This theory also ignores the various results suggesting that phonological codes activate orthographic representations during reading, via feedback (e.g., Stone et al., 1997).
  
4. On the present theory, abstract orthographic codes cannot be acquired without consistent feedback from phonological and semantic representations. However, after these abstract codes are learned, the feedback is no longer necessary in order to match different versions of the same letter or word.

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Table 1

Mean Lexical Decision Latencies (ms) and Error Rates as a Function of the Study/Test Condition in Experiments 1-2 . Priming scores in brackets.

Study/Test Condition	RTs (ms)	% Errors
Experiment 1		
Hiragana/Hiragana	632 (32)	1.9 (1.6)
Kanji/Hiragana	632 (32)	3.3 (.02)
Spoken/Hiragana	653 (10)	1.9 (1.6)
Nonstudied/Hiragana	663	3.5
Experiment 2		
Kanji/Kanji	419 (25)	2.7 (3.2)
Hiragana/Kanji	427 (17)	3.9 (2.0)
Spoken/Kanji	441 (03)	6.1 (-.2)
Nonstudied/Kanji	444	5.9

Figure Captions

Figure 1. Examples of Hiragana and Kanji words used in Experiment 1, with English translations.

Figure 2. The visual patterns A and a each map onto the phonological code /ei/, which results in the co-activation of A and a each time one of the patterns is presented, via feedback. Associative learning principles within the orthographic system act to map together these co-active patterns to produce an abstract letter code.

Figure 1

Hiragana	Kanji	English Translation
		liquor
		fish
		meat
		mathematics
		school

Figure 2

