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NORMAL AND IMPAIRED READING OF JAPANESE KANJI AND KANA

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ABSTRACT

Two kinds of scripts are used in the written forms of Japanese words: morphographic kanji and phonographic kana. Whereas each kana character invariably represents a single pronunciation, the majority of kanji characters have two or more legitimate pronunciations, with one appropriate to the character in any given word. Furthermore, each kanji character has meaning while a kana character does not. On the basis of these and other differences between kanji and kana, some traditional views assume that, in reading aloud, kanji is processed by a semantic/lexical system while kana is processed by a phonological/rule system.

We review accumulating evidence from our research that argues against these traditional views. (1) In reading aloud two-character kanji words, normal readers are slower on low-frequency words with statistically atypical character-sound correspondences than either high-frequency words or words with statistically typical correspondences. (2) Normal readers are easily capable of reading aloud two-character kanji non-words. (3) Normal readers are slower on low-imageability words than high-imageability words, but the imageability effect emerges only for low-familiarity kanji words with atypical character-sound correspondences. (4) Although Japanese surface dyslexia has been described as a selective reading disorder on kanji words, recently reported cases reveal good kanji performance for high-frequency words and words with statistically typical correspondences, despite a profound deficit on low-frequency words with atypical character-sound correspondences.

(5) In reading aloud kana nonwords, normal readers are faster on pseudohomophones (orthographic nonwords with a familiar phonological pattern, created by transcribing kanji words into kana strings) than nonwords not homophonic with any words, but this significant advantage emerges only when the pseudohomophones share their pronunciations with high-imageability words. (6) Although Japanese phonological dyslexia has been considered a selective reading disorder on kana nonwords, a recently reported case showed good performance on pseudohomophones with the identical pronunciation to high-familiarity and high-imageability words, despite a profound deficit on nonhomophonic nonwords.

These data suggest that phonology of both kanji and kana strings is computed directly from orthography, with additional reliance on semantics when the direct computation is inefficient.

1. JAPANESE ORTHOGRAPHY

The spoken form of a Japanese word comprises a sequence of from one to several morae (e.g., /ni-ho-N/ "Japan"). A mora corresponds to a single vowel (V), a consonant-vowel compound (CV), a palatalized consonant-vowel compound (CjV), the nasal coda (N) which can follow a V, CV, or CjV mora, or a geminate consonant (Q: its acoustic entity is, for example, a prolonged silent period before the following plosive consonant). Two kinds of scripts are used in the written forms of Japanese words: morphographic kanji and phonographic kana.

Kanji comprises approximately 6,000 characters, with about half of these used in daily life. Some kanji characters appear as a single-character noun (空 /sora/ "sky"), as a component of multiple-character kanji nouns (空気 /kuu-ki/ "air", 空色 /sora-iro/ "sky blue", 空手 /kara-te/ "Japanese traditional fight"), and as the stems of kanji-kana compound verbs (空く /a-ku/ "become vacant") and adjectives (空しい /muna-si-i/ "fruitless"). Other characters appear only in one, two, or three of these written word classes. A kanji character does not reliably map to any specific size of phonological unit like a phoneme, a mora, a syllable, or a word, and cannot be decomposed into elements which correspond to phonemes or morae. The majority of kanji characters have two or more legitimate pronunciations, which generally contain from one to three morae, with the one pronunciation appropriate for the character in any given word determined by intraword context. The pronunciations of a kanji character can be divided into ON and KUN. When kanji characters were imported from China, their pronunciations also entered the Japanese spoken language; an ON pronunciation (or ON-reading) derives from the pronunciation of an original Chinese character (e.g., /kuu/ for 空 in 空気 /kuu-ki/). A KUN pronunciation (or KUN-reading), on the other hand, derives from the pronunciation of an original spoken Japanese word which has the same meaning as the Chinese character (e.g., /sora/ for 空). Because Chinese and Japanese are completely different spoken languages, there is usually no phonological similarity between the ON and KUN pronunciations of any given kanji character. Furthermore, a kanji character represents not only its phonology but also its semantic domain. For example, a meaning related to "sky", "empty", or "vacant" seems to be shared across the words including 空 even if the pronunciations for 空 vary across the words.

Kana is sub-divided into hiragana (cursive form) and katakana (square form). Hiragana is used for most function words (そして /so-si-te/ "and"), some content words (りんご /ri-N-go/ "apple"), and the inflections of verbs (空く /a-ku/ "become vacant") and adjectives (空しい /muna-si-i/ "fruitless"), whereas katakana is used for loan words (テスト /te-su-to/ "test") from western languages. Both hiragana and katakana comprise 75 characters, and there is always a pair of hiragana and katakana characters representing the same pronunciation. A kana character usually maps to a single mora of spoken Japanese: Five characters correspond to a single vowel (e.g.,あ /a/), 65 correspond to a consonant-vowel compound (e.g., き /ki/, や /ja/), one corresponds to a nasal coda (ん /N/), and one corresponds to gemination (っ /Q/). Although three kana characters do not correspond to morae on their own, these indicate both the palatalization of the consonant of the previous CV mora and the vowel change (ゃ in きゃ /kja/) in a totally predictable manner. Thus, character-sound correspondences in kana are perfectly transparent, and do not vary across different intraword contexts. Furthermore, because individual kana characters do not inherently represent meaning, visually similar monomorphemic kana words share no semantic similarity (もし /mo-si/ "if", うし/u-si/ "cow", けし /ke-si/ "poppy"), except for some deictic words (これ /ko-re/ "this", それ/so-re/ "it", あれ /a-re/ "that") and some suffixes.

2. MODELS FOR KANJI AND KANA READING

On the basis of the kinds of differences between kanji and kana summarized above, some traditional views assume that the process of computing phonology from orthography for the two scripts is qualitatively different. This view has been supported by neuropsychological evidence that, among a population of Japanese acquired dyslexic patients, some show a more salient deficit on kanji than kana in reading aloud, and others vice versa [e.g., 1]. A neuropsychological model [2] assumes that two different neural pathways from the visual area of the occipital lobe to Wernicke's area are differentially involved in reading of kanji and kana: a ventral pathway passing through the posterior part of the middle and inferior temporal gyri is described as the semantic reading pathway indispensable for reading kanji words, whereas a dorsal pathway via the angular gyrus is thought to be responsible for the phonological processes involved in kana. Some cognitive models [e.g., 3, 4], akin to "dual-route" models [e.g., 5], assume that kanji words and high-frequency kana words are processed by a lexical route which operates by activating whole-word orthographic, phonological (and possibly also semantic) representations. Low-frequency kana words and kana nonwords, by contrast, are supposed to be translated into phonology by a non-lexical procedure consisting of kana-mora correspondence rules. These models seem to presume that kanji is almost exclusively handled by a semantic/lexical system whereas kana is mainly handled by a phonological/rule system.

We propose, in this paper, an alternative cognitive model for kanji and kana reading. Our proposal is based on the "triangle" model of word processing (Figure 1), originally suggested by Seidenberg and McClelland [6] for explaining various phenomena in reading English words, and elaborated, especially in terms of implementation as a computational model, by Plaut et al. [7]. This model assumes that, in each of the three labeled domains of word knowledge in Figure 1, a word is represented as a pattern of activity over processing units shared across similar words. On the basis of connections between units within and between domains, whose strengths have been determined during learning, the model performs a linguistic task by computing one representation from another: speech comprehension (the computation of semantics from phonology, hereinafter the *phon-sem* computation), speech production (the *sem-phon* computation), reading comprehension (*orth-sem*), reading aloud (*orth-phon*), speech repetition (*phon-phon*: the recurrent computation of phonology), and so on. Furthermore, because any computation in the model proceeds in a gradual and interactive manner, some interactions involving all representations emerge: for example, phonology can be computed from semantics which has been already computed from orthography (*orth-sem-phon*) or phonology generated from the *orth-phon* computation is reinforced by the communication between phonology and semantics (*orth-phon-sem-phon*).

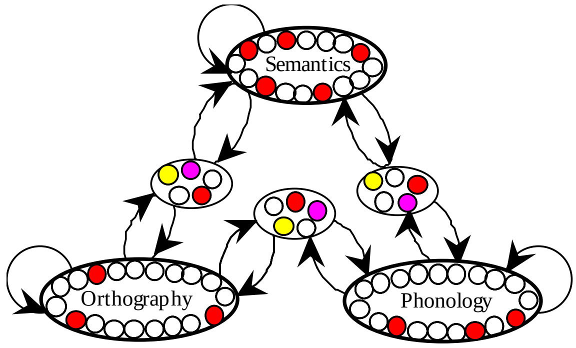

Figure 1: The triangle framework of word processing. Based on Seidenberg & McClelland (1989). Circles indicate processing units, ovals indicate a pool of units in the same domain, and arrows indicate connections between units.

Our assumption in applying the triangle framework to Japanese kanji and kana reading is that any orthographic string, whether it comprises kanji or kana or both and whether it represents a word or nonword, is processed by the same mechanisms. We do not, therefore, preclude any computational process for any script. In the following sections, amongst many computations in the triangle model, we will review the evidence for two particular processes which have been controversial: the computation of *orth-phon* for kanji strings and the computation of *orth-phon-sem-phon* for kana strings. In both cases, this evidence includes the performance of normal readers and also patients with acquired dyslexia.

3. READING ALOUD KANJI

3.1. Normal Readers

Some recent studies of normal readers' performance have demonstrated the contribution of the *orth-phon* computation to reading aloud for kanji words [8, 9, 10]. For example, Fushimi et al. [8] analyzed a corpus of 31,000 two-character kanji words containing more than 3,000 kanji characters, and found that 40% of characters have a single, invariant pronunciation across the set of orthographic neighbors sharing the same character at the same position (hereinafter, *the neighbors*). Even for characters which have more than one legitimate pronunciation across neighbors, the statistically most typical pronunciation can be identified by counting the number of words sharing the same pronunciation for the shared character. In this study, a word was classified as *consistent* if each constituent character has the identical pronunciation across the neighbors. A word was classified as *inconsistent-typical* if each constituent has more than one legitimate pronunciation across the neighbors but it is the statistically typical pronunciation of each character that is appropriate to this target word. A word was classified as *inconsistent-atypical* if each constituent has more than one legitimate pronunciation and one or both character pronunciations appropriate to this target word are not statistically typical. In an experiment employing 120 two-character kanji words, with 20 words in each of the six conditions formed by crossing three bands of consistency with two bands of word frequency (high vs. low), the performance of the normal readers revealed a frequency by consistency interaction, with latencies to low-frequency inconsistent-atypical words significantly slower than those for any of the other five conditions.

These effects of frequency and consistency observed in normal readers' performance are well interpreted by a computational network which translates orthography into phonology for two character kanji-words. Ijuin et al. [11] developed a network consisting of the bottom part of the triangle model (Figure 1): the orthography units, the intermediate or “hidden” units, the phonology units, and connections between these sets of elements. After the completion of training with a corpus of approximately 4,000 two-character kanji words, the network could compute the correct pronunciation of all words in the corpus (99.8%) except for a few heterophonic homographs. At this point, the network — just like the human readers reported in [8] — was less efficient in computing phonology for low-frequency inconsistent-atypical words than for any other condition. As pointed out in many simulation studies using this kind of approach [e.g., 6, 7], the network is sensitive to word frequency because, during the course of training, the amount of connection-strength adjustment for each word is proportional to the word’s frequency. The network is sensitive to consistency of character-sound correspondences because the adjustment of connection strengths relevant to a given word is also appropriate for neighbors in which the same character has an identical pronunciation, whereas it is inappropriate for neighbors sharing the same character but with a discrepant pronunciation. Thus, the *orth-phon* computational network shows the least efficient performance for low-frequency inconsistent-atypical words because these words enjoy little benefit of training on either themselves or their neighbors.

Furthermore, Fushimi et al. [8] assessed normal readers' performance on reading aloud kanji nonwords. Nonwords were created by re-combining the first character of a two-character kanji word with the second character of another two-character kanji word to form non-existing two-character kanji strings. The correct pronunciation of a consistent nonword, in which each constituent character has a single legitimate pronunciation across real words sharing the same character at the same position as the nonword, was defined as the concatenation of the single pronunciations for the first and the second character. The correct pronunciation for an inconsistent nonword, in which each constituent character has more than one legitimate pronunciation across the real-word neighbors, was defined as any concatenation of legitimate pronunciations for the constituent characters. In an experiment employing 120 two-character kanji nonwords comprising 40 consistent nonwords and 80 inconsistent nonwords, normal readers read aloud these nonwords with 89% accuracy (92% for consistent nonwords and 87% for inconsistent nonwords).

These results from normal readers and the *orth-phon* computational network do not constitute any denial of a role for word meaning in reading aloud kanji words. Fushimi et al. [12] investigated the joint contribution of semantics and *orth-phon* consistency to reading aloud two-character kanji words. The semantic variable manipulated was imageability, which was measured by subjective ratings of the ease with which a given word arouses a mental image. In general, words with concrete referents (like APPLE) have higher imageability scores than abstract words (like LOGIC). In the experiment employing 160 two-character kanji words (Figure 2), with 20 words in each of the eight conditions formed by crossing two bands of familiarity (high vs. low) [13], two bands of consistency (consistent vs. inconsistent-atypical), and two bands of imageability (high vs. low) [14], normal readers were slower on low- than high-familiarity words, and slower on inconsistent-atypical than consistent words. An imageability effect emerged only for low-familiarity inconsistent-atypical words, where high-imageability words yielded shorter latencies than low-imageability words. As demonstrated in the network’s performance [11], the *orth-phon* computation is efficient for both high-familiarity and consistent words, for which the semantic contribution might be too redundant to be detected. These results indicate that phonology of two-character kanji words is computed directly from orthography with additional support from semantics when the *orth-phon* computation is inefficient. The activation of semantic representations in reading aloud may arise from either or both of the *orth-sem* and the *orth-phon-sem* computations. We have no current data which evaluates the relative contributions of these computations, and this issue should be addressed in future research.

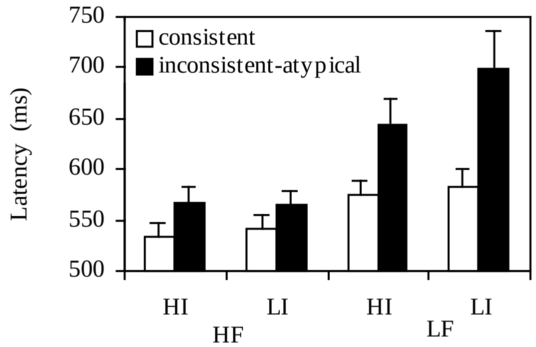

Figure 2: Mean latencies and standard errors for normal readers in reading aloud kanji words. HF: high-familiarity; LF: low-familiarity, HI: high-imageablity, LI: low-imageablity. Adapted from Fushimi et al. (1998).

3.2. Surface dyslexia

Surface dyslexia (or alexia) as observed in English-speaking patients is an acquired disorder of reading in which patients show difficulty in reading aloud words that violate typical spelling-sound correspondences (exception words like PINT). In contrast, they have relatively, or sometimes even perfectly, preserved ability to read aloud letter strings in which the assignment of the typical pronunciation for each component yields the correct pronunciation for the whole string (viz., regular words like MINT and nonwords like ZINT). The dominant type of incorrect reading produced by these patients has been characterized as a LARC error (Legitimate Alternative Reading of Components) [15], in which the pronunciation of one or more components is inappropriate for the target word but is nonetheless legitimate for that component in other words from the target’s orthographic neighborhood (e.g., reading PINT to rhyme with MINT). Furthermore, because most if not all of the pure cases of surface dyslexia reported have also exhibited profound anomia and comprehension deficits, the pattern of reading impairment in these patients seems to be associated with a disruption to semantic memory or to the communication between semantics and phonology. Based on the triangle framework, Plaut et al.[7] accounted for this association by demonstrating that, although the *orth-phon* computational network developed without semantic support is able to compute correct pronunciations even for low-frequency exception words, the *orth-phon* network developed with additional semantic input to phonology (perhaps as in the case of most human readers) becomes sufficiently dependent on this additional source of constraint in processing low-frequency exception words as to be surface dyslexic when the semantic support is withdrawn.

Japanese surface dyslexia has traditionally been thought to consist of preserved ability to read aloud kana words and kana nonwords, coupled with a selective deficit in reading aloud kanji words which results from damage to the semantic/lexical system [1]. As described in Section 3.1, however, the direct *orth-phon* computation, which is efficient for both high-frequency and consistent kanji words, has proved to play a substantial role in reading aloud kanji words. Furthermore, if the *orth-phon* computation in human readers has developed to depend on additional semantic constraints in settling on a correct pronunciation for less common words with atypical character-sound correspondences, it is predicted not only that Japanese surface dyslexic patients suffering from semantic impairment should show a more severe disturbance in reading kanji than kana words, but also that the severity of the deficit in reading kanji words should be modulated by both frequency and consistency. These predictions are confirmed by the performance of several recently reported Japanese surface dyslexic patients [15, 16].

Patterson et al. [15] described a striking case of Japanese surface dyslexia, patient NK, who showed profound anomia and comprehension deficit especially for low-frequency words. Her performance in reading kana strings was flawless both for words and nonwords, in contrast to a significant deficit in reading kanji words. The authors prepared materials to capture the surface dyslexic pattern mentioned in the prediction above. These comprised 160 two-character kanji words (Figure 3), with 20 words in each of the eight conditions formed by crossing two bands of frequency (high vs. low) with four bands of consistency (consistent, inconsistent-typical, inconsistent-atypical, and exception). They employed the ON-KUN difference in evaluating the consistency of character-sound correspondences [cf. 9]. Among about 32,000 two-character kanji words, those in which an ON pronunciation is correct for each constituent character (85%) substantially predominate over those in which the KUN pronunciation is correct for each constituent character (11%) [13]. Consistent words in this experiment were those in which each constituent character has a single legitimate ON pronunciation. Inconsistent-typical words were those in which each constituent character has both legitimate ON and KUN pronunciations but the standard ON pronunciation is appropriate for each character in this target. Inconsistent-atypical were words in which each constituent character has both legitimate ON and KUN pronunciations but the KUN pronunciation is appropriate for each character in this target. Exception words were those in which the whole-word pronunciation is unique and cannot be divided into components corresponding to the constituent characters. As shown in Figure 3, NK made many errors on low-frequency inconsistent-atypical words and exception words, with substantially fewer misreadings of high-frequency kanji words and of low-frequency consistent and inconsistent-typical words. Of her errors on inconsistent-atypical and exception words, 84% were LARC errors, in which NK produced inappropriate but legitimate pronunciations for constituent characters in a word. Nakamura et al. [16] reported extremely similar results with other surface dyslexic patients, employing statistically defined consistency of character-sound correspondences similar to that in Fushimi et al. [8].

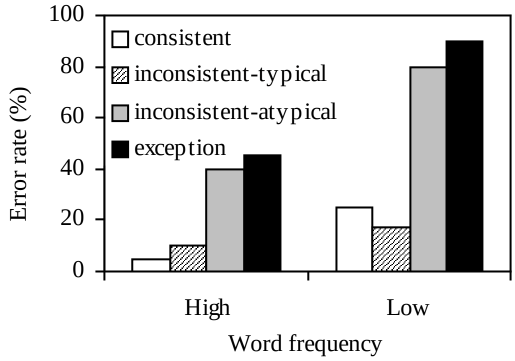

Figure 3: Percentage error for NK in reading two-character kanji words. Adapted from Patterson et al. (1996).

4. READING ALOUD KANA

4.1. Normal Readers

It seems clear that the *orth-phon* computation for kana strings is very efficient, as indicated in part by the preserved reading performance for kana strings in surface dyslexic patients [15, 16]. Nevertheless, as described in Section 2, we do not preclude the possibility that other types of computation are also involved in reading kana strings. One candidate of interest is the *orth-phon-sem-phon* computation. As described in Section 3.1, however, a semantic contribution to the *orth-phon* computation was not apparent even for kanji words if they were either high-familiarity or consistent, presumably because the *orth-phon* computation on its own for these words is so efficient as to mask any additional effect of *sem-phon* activation. Therefore, we predict that the semantic contribution to reading kana should appear primarily in kana strings for which the *orth-phon* computation is somewhat weaker than usual, but the *phon-sem*, *sem-phon*, and *phon-phon* computations are strong. These strings are kana pseudohomophones with pronunciations identical to high-familiarity and/or high-imageability words.

A pseudohomophone is an orthographic nonword with a familiar phonological pattern like HOAP and JOAK in English. These letter strings do not exist in the English written vocabulary but their phonology exists in the English spoken vocabulary because HOAP and JOAK are homophonic with HOPE and JOKE, respectively. Readers' performance for these pseudohomophones should be compared with nonhomophonic nonwords like HOAK and JOAP because letters and phonemes are then exactly matched between pseudohomophones and nonhomophonic nonwords [17]. In Japanese, pseudohomophones can be created by transcribing a real word normally written in kanji into kana. Fushimi et al. [18] prepared materials similar to the English examples mentioned above: 240 katakana strings, with 40 strings in each of the six conditions formed by crossing three bands of lexicality (words, pseudohomophones, and nonhomophonic nonwords) with two bands of imageability (high vs. low). Words were four-character and four-mora katakana loan words. Four-mora kanji words were transcribed into katakana strings to yield four-character and four-mora pseudohomophones. Half of the katakana words and half of the kanji words from which the pseudohomophones were created had high-imageability ratings while the other half were low-imageability words. Words in these four conditions (high- and low-imageability katakana words, and high- and low-

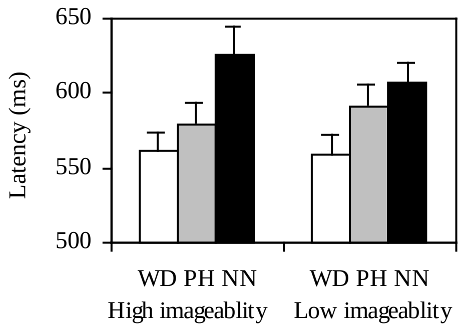

Figure 4: Mean latency and standard errors for normal readers in reading aloud katakana strings. WD: word, PH: pseudohomophone, NN: nonhomophonic nonword. Adapted from Fushimi et al. (2000)

imageability kanji words) were equated in terms of mean aural familiarity (familiarity ratings to spoken words) [13]. Nonhomophonic nonwords were created by re-combining the first and the second characters of a pseudohomophone with the third and the fourth characters of another pseudohomophone, within the same imageability band, to yield a meaningless katakana string not homophonic to any word. Figure 4 shows the mean latency for normal readers in reading aloud katakana strings in each of the six conditions. In the high-imageability condition, not surprisingly the normal readers were faster to read aloud real words than either type of nonword; but of greater relevance here, they were significantly faster to produce PH than NN pronunciations. In the low-imageability condition, there was an orthographic lexicality effect (words faster than both types of nonword) but no significant advantage for PH relative to NN strings.

These results are well interpreted by the triangle model. Kana characters have such consistent character-sound correspondences that the *orth-phon* computation can readily generate the correct pronunciation of any kana strings, whether they are words or nonwords. However, the model is still less efficient for nonwords than words because the phonology of a given nonword must be computed with reference to connection strengths adjusted, not for the nonword itself, but for orthographically similar words sharing characters with the nonword. Thus, the orthographic lexicality effect should emerge, in which words are always better than nonwords whether nonwords are pseudohomophones or nonhomophonic nonwords. The pseudohomophone advantage does not arise from the *orth-phon* computation, because pseudohomophone and nonhomophonic nonwords are processed with equal efficiency in this pathway as long as they are equated in terms of orthographic similarity to real-word neighbors. It arises from the *phon-sem-phon* computation (and perhaps also from the *phon-phon* computation) because the phonology of pseudohomophones is identical to words for which the *phon-sem* and *sem-phon* computations are highly trained in speech comprehension and production, respectively, and because these computations are apparently more efficient for high- than low-imageability words.

4.2 Phonological dyslexia

Phonological dyslexia observed in English-speaking patients is an acquired disorder in which reading aloud for nonwords is markedly impaired relative to real words. These patients typically show an advantage for pseudohomophones over nonhomophonic nonwords, indicating that the deficit on nonwords arises from phonological as well as orthographic lexicality. Furthermore, the difficulty in processing nonhomophonic nonwords is observed not only in reading aloud but also in phonological manipulation tasks (e.g., phoneme segmentation or blending), which do not employ written stimuli. On the basis of these phenomena, some researchers assume that the deficit of nonword reading is just one manifestation of a general phonological impairment [e.g., 7, 19].

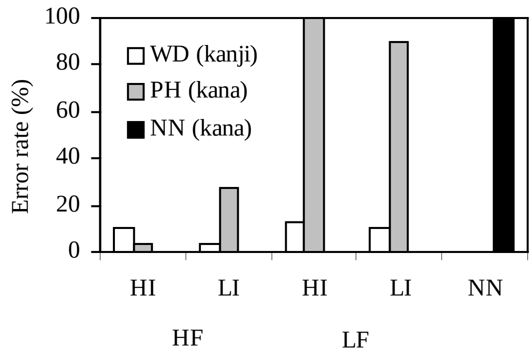

Figure 5: Percentage error for KT in reading aloud kanji words (WD), hiragana pseudohomophones (PH), and hiragana nonhomophonic nonwords (NN). HF: high familiarity, LF: low familiarity; HI: high imageablity, LI: low imageablity. Adapted from Patterson et al. (1996).

Japanese phonological dyslexia has been thought to consist of preserved reading of kanji and kana words, coupled with a selective disturbance of reading aloud kana nonwords owing to impaired or even abolished knowledge of kana-mora correspondence rules. However, if this deficit results from a general phonological impairment, it is predicted that phonological dyslexic patients should show (a) the lexicality advantage in a task which does not employ written materials, and (b) a pseudohomophone advantage in reading aloud kana nonwords. Furthermore, the contribution of the *phon-sem-phon* computation, as demonstrated in the performance of normal readers, should modulate the pseudohomophone advantage according to the imageability (and also familiarity) of the words with which the pseudohomophones share their pronunciations. These predictions were confirmed by the performance of a recently reported Japanese phonological dyslexic patient, KT [20].

KT's accuracy of reading aloud both kanji words and kana words was about 90% while that for kana nonwords was 0%. In a phonological blending task, where KT was given a sequence of spoken morae presented separately with pauses in between and required to blend them into a fluently uttered chunk of speech, he succeeded when the required response formed a word (100% correct) but often failed when it formed a nonword (57%). The authors also investigated the possibility of a pseudohomophone advantage in KT's reading aloud of hiragana strings. They prepared 120 kanji words, with 30 words in each of the four conditions formed by two bands of familiarity (high vs. low) and two bands of imageability (high vs. low). The pseudohomophones were created by transcribing these kanji words into hiragana strings. Figure 5 shows KT's error rate on the original kanji words and hiragana pseudohomophones varying familiarity and imageability, along with his error rate on nonhomophonic nonwords (although these nonhomophonic nonwords were not matched to the pseudohomophones in terms of the characters comprising them). Pseudohomophones created from high familiarity, and especially from high-familiarity and high-imageability kanji words, yielded impressively preserved performance relative to nonwords and to pseudohomophones created from low-familiarity words.

5. CONCLUSION

We have summarized recent empirical evidence for the contribution of the direct *orth-phon* computation to reading aloud kanji words. In experiments employing two-character kanji strings, (1) the consistency of character-sound correspondences as well as word frequency influenced the speed of normal readers in reading words, (2) normal readers were easily capable of reading aloud nonwords, (3) an imageability effect on reading words emerged only for low-familiarity kanji words with atypical character-sound correspondences, and (4) consistency as well as frequency substantially influenced reading accuracy for surface dyslexic patients. We also reviewed evidence for the contribution of the *phon-sem-phon* computation to reading aloud kana nonwords, as demonstrated in a pseudohomophone advantage modulated by imageability, both in (5) the speed of normal readers and (6) the accuracy of a phonological dyslexic patient.

These data are inconsistent with the traditional views which assume two separate processes in reading aloud Japanese, one for kanji (or kanji words) and the other for kana (or kana nonwords) [1, 2, 3]. These views should be modified so that kanji words are processed by both a semantic/lexical and a phonological/ rule system by specifying how the latter system operates for kanji. Furthermore, these views should incorporate interactivity between processes or representations, as in the computational version of the English dual-route model [5], to account for a semantic impact on reading aloud kanji words and kana pseudohomophones. In an alternative interpretation, the data summarized here suggest that, either for words or nonwords, the phonology of both kanji and kana strings is computed directly from orthography, with additional reliance on activation from word meaning when the direct *orth-phon* computation is inefficient. This suggestion is easily captured in the triangle framework as described in this paper. Although the empirical data on kanji and kana reading are not yet sufficient to adjudicate between the dual-route and triangle models, it should be noted that Ijuin et al. [21] have already proceeded to develop a working computational model based on the triangle approach, which successfully simulates a substantial amount of the data reviewed here.

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