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The time-course of lexical activation in Japanese morphographic word recognition: Evidence for a character-driven processing model

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Abstract

This lexical decision study with eye-tracking of Japanese two-*kanji*-character words investigated the order in which a whole two-character word and its morphographic constituents are activated in the course of lexical access, the relative contributions of the left and the right characters in lexical decision, the depth to which semantic radicals are processed, and how non-linguistic factors affect lexical processes. Mixed-effects regression analyses of response times and subgaze durations (i.e., first-pass fixation time spent on each the two characters) revealed joint contributions of morphographic units at all levels of the linguistic structure with the magnitude and the direction of the lexical effects modulated by readers' locus of attention in a left-to-right preferred processing path. During the early time frame, character effects were larger in magnitude and more robust than radical and whole word effects, regardless of the font size and the type of nonwords. Extending previous radical-based and character-based models, we propose a task/decision-sensitive character-driven processing model with a level-skipping assumption: Connections from the feature level by-pass the lower radical level and link up directly to the higher character level.

Key words: visual word recognition; morphological processing; Japanese; lexical decision; eye movement

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The time-course of lexical activation in Japanese morphographic word recognition: Evidence for a character-driven processing model

Studies on the recognition of complex entities, irrespective of whether these are scenes, objects, or human faces, need to consider how the whole and its parts contribute to our recognition of the input as a coherent meaningful unit (Beck, 1966; Biederman, Mezzanotte, & Rabinowitz, 1982; Greene & Oliva, 2009; Joseph & Tanaka, 2003; Kahneman, Treisman, & Gibbs, 1992; Navon, 1977; Tanaka, Kiefer, & Bukach, 2004; Treisman & Gelade, 1980; Wachsmuth, Oram, & Perrett, 1994). Word recognition is no exception in this respect. Some researchers have argued that morphologically complex words are represented and processed as wholes (Aitchison, 1987; Butterworth, 1983; Caramazza, Laudanna, & Romani, 1988; Janssen, Bi, & Caramazza, 2008). In the word-based supralexical model of Giraudo and Grainger (2001), the activation of the whole word precedes the activation of the constituent parts.

Many others believe that there is a rapid and automatic morphological decomposition process in recognition and production. In this view, word recognition is not a simple process matching whole word forms to whole word meanings: Sublexical units are posited to exist and also play a role in recognition. There remains, however, an on-going debate over how and at what point in time sublexical units contribute to lexical access (see Frost, Grainger, & Carreiras, 2008; Frost, Grainger, & Rastle, 2005, for overviews). Strict morpheme-based theories of lexical access in reading claim that complex words are decomposed into their constituents and subsequently recombined into a whole word representation (Taft, 2004; Taft &

Forster, 1975; Taft & Nguyen-Hoan, 2010). Although interactive activation models allow top-down feedback, bottom-up combinatorial processing is a dominant characteristic of these models as well (McClelland & Rumelhart, 1981; Taft, 1994).

Yet other models proceed on the assumption that the whole and its parts are accessed in parallel (Baayen, Dijkstra, & Schreuder, 1997; Diependaele, Duñabeitia, Morris, & Keuleers, 2011; Frauenfelder & Schreuder, 1992; Kuperman, Schreuder, Bertram, & Baayen, 2009; Pollatsek, Hyönä, & Bertram, 2000). Although efficiency in lexical processing has often been discussed in terms of the dichotomy of computational efficiency and storage efficiency (McClelland & Patterson, 2002a, 2002b; Pinker & Ullman, 2002a, 2002b), it has also been argued that it is efficient to redundantly represent and activate all constituent morphemes, as well as whole word units, thus maximizing opportunities for word identification (Libben, 2006). Previous eye-tracking studies provided partial support for such parallel-route architecture. Pollatsek et al. (2000) tracked eye-movements when Finnish compounds were read in sentences. Although a complete decompositional model predicts a whole compound frequency effect to appear later than an effect of the second constituent frequency, the study found that whole compound frequency effect appears at least as early as the second constituent frequency effect, indicating a race between a decompositonal route to activate the constituents and a direct route to activate the whole compound. Kuperman et al. (2009) more recently combined lexical decision with eye-tracking and observed simultaneous contributions of whole word frequency and morphological constituent frequency already at the first fixation, before the entire word had been scanned. These results challenge strict hierarchical processing models but are compatible with both non-hierarchical multiple route models and with hierarchical models that allow lower level units to connect with higher level units while skipping intermediate levels.

Morphographic word recognition

The writing systems of Chinese and Japanese add various layers of complexities to the current theories developed for English and other related languages. Morphographic orthographies make use of very large numbers of symbols. The minimal basic set of characters taught in Japanese compulsory education comprises 1,945 distinct characters (Japanese Ministry of Education, Culture, Sports, Science and Technology, 2009). The Japanese industrial standard (JIS) list of characters for computers includes 6,353 characters, and ordinary Japanese and Chinese morphographic character dictionaries contain well over 10,000 characters (Coulmas, 2003; Kess & Miyamoto, 1999). Unlike alphabetic letter symbols, Japanese morphographic characters directly encode meaning (e.g., 木 /ki/ ‘wood’).

Although *kanji* characters have often been compared to morphemes in alphabetic languages, the majority of characters are themselves decomposable into smaller units. The character 海 /kai/ ‘sea’, for example, consists of a semantic radical 氵 and a phonetic radical 毎. Among 2,965 Japanese Industrial Standard *kanji* characters, 83% of the characters consist of either left and right radicals or top and bottom radicals (Saito, Kawakami, & Masuda, 1995, 1997). Semantic radicals encode a general basic category meaning. The radical 氵 ‘water’, for example, is shared by characters whose meaning is associated with ‘water’ (e.g., 海 ‘sea’, 液 ‘liquid’, and 酒 ‘liquor’), although the contribution of the semantic radical to the whole character is not always transparent (e.g., 法 ‘law’ is not related to ‘water’). Phonetic radicals, on the other hand, encode approximate information about the pronunciation of the character (e.g., 海 and 悔 are both pronounced /kai/). The different functions of semantic and phonetic radicals are explicitly taught in primary school.

When they encounter unfamiliar words, readers of Japanese can rely on the radicals. For example, an unfamiliar two-character word such as 寒鰤 ‘winter yellowtail’, which appeared only once in 14 years of newspaper texts (Amano & Kondo, 2003), is relatively well-interpretable thanks to the right character’s semantic radical 魚 ‘fish’ and the left character 寒 ‘cold’, even though the reader may not know what the phonological form of the Japanese word is (/kanburi/; the /n/ denotes a moraic nasal). A large majority of Japanese words are written with two *kanji* characters (70% as estimated by Yokosawa & Umeda, 1988). A question addressed in this study is how readers process radical and character information in comprehending relatively familiar two-character words.[1]

Several experimental studies suggest that the characters in two-character words are accessed in reading. Hirose (1992), observing a stronger priming effect of the left character over that of the right character in primed lexical decision, proposed that two-character words are represented in clusters centered around the shared left character, and that they are processed from left to right, with the left character functioning as the retrieval cue. While this perspective appears to be in line with importance of the initial constituent reported by Taft and Forster (1976) for English and Yan et al (2006) for Chinese, Tamaoka and Hatsuzuka (1995) and Zhang and Peng (1992), in contrast, reported that the frequency of the right character facilitates two-character lexical decision responses more than the left character in Chinese and Japanese respectively. Kawakami (2002) reported facilitation from the type frequency of characters in two-character word lexical decision.[2] In addition to character frequency effects, Tamaoka (2005) observed that larger numbers of homophones associated with the left character lead to longer response times in lexical decision and naming. Tamaoka and Hatsuzuka (1998, lexical decision and naming) further reported that semantic/conceptual properties of characters co-determine word recognition responses (cf. Ji & Gagné, 2007, sense-nonsense judgment with English compounds).

A separate series of studies has addressed the role of radicals in single-character words. Taft and Zhu (1997) reported that higher type frequency of the right radical speeds up character decision. Feldman and Siok (1997) similarly reported facilitatory effects of radical type frequency, but they considered the function of radicals (i.e., semantic vs. phonetic), rather than their positions. They observed that a greater type frequency of the semantic radical facilitated character decision when the radical is located in the left position of the character. Feldman and Siok (1999) further argued, from primed character decision data, that the meaning of the semantic radical is co-activated. A contribution of radicals also has been reported in speeded semantic categorization (Flores d'Arcais & Saito, 1993) and in word naming (Flores d'Arcais, Saito, & Kawakami, 1995).

(Insert Figure 1 around here)

In the present study, we primarily test the predictions of the two hierarchical models of morphographic two-character word recognition shown in Figure 1. The character-based model (left, Tamaoka & Hatsuzuka, 1998) claims that characters are the basic lexical units, whereas the radical-based model (right, Ding, Peng, & Taft, 2004; Saito, 1997; Saito, Masuda, & Kawakami, 1998; Taft & Zhu, 1997; Taft, Zhu, & Peng, 1999) assumes that radicals mediate between strokes and characters. Both models presuppose left-to-right scanning of the visual input (Taft & Zhu, 1997; Tamaoka & Hatsuzuka, 1995), and both assume that a higher level unit can only be activated once its lower level constituent units are activated.

The two models diverge with respect to the role of radicals. Taft et al. (1999) and Saito (1997) argue that morphographic characters are initially decomposed into radicals. In models that distinguish characters and radicals, an issue at stake is whether semantic radicals are semantically interpreted as soon as they are activated. Taft et al. (1999) assume that characters form the first level in the hierarchy that provides access to meaning. In other words, in this model, radicals function as purely orthographic access codes. However, there is some experimental evidence suggesting that semantic radicals are interpreted semantically as soon as they have been activated. (Feldman & Siok, 1997, 1999; Miwa, Libben, & Baayen, 2012). The evidence for the two models in Figure 1 comes from two distinct streams of research. Evidence for characters as processing units was obtained with experiments using two-character words, while evidence for radicals as processing units was obtained using single-character words. Miwa et al. (2012) performed the first study addressing the role of semantic radicals in the processing of two-character words. In their lexical decision study with partial repetition priming of the semantic radical in the right character, a significant interaction was observed between the priming manipulation and the semantic properties of the semantic radicals, suggesting that even in two-character words, an effect of semantic radicals can be detected.

Goals of this study

The studies reviewed in the previous section involved 15 lexical decision experiments, all based on only 30 to 90 target words (*M* = 51, *SD* = 17.8) matched on a limited number of experimental variables. As Cutler (1981) pointed out three decades ago, it is a “confounded nuisance” to pre-experimentally control for the growing number of all potentially important variables, and we will be lost for words. For example, Yan et al., (2006) manipulated frequencies of words and characters in a 2*2*2 design with strokes and radical frequencies controlled; each of the eight conditions consequently contained only six words. If radical frequencies were also to be manipulated, in theory, 32 conditions would be necessary. While Tamaoka (2005, 2007) carefully controlled for a relatively large number of 11 and 18 potentially important variables, all the other studies controlled for a much smaller number of variables. Pre-experimental matching on numerical covariates may lead to substantial loss of statistical power (Baayen, 2010; Cohen, 1983; MacCallum, Zhang, Preacher, & Rucker, 2002), and may negatively affect the representativeness of the sampled items. We therefore opted for a regression design analyzed with mixed-effects models (Baayen, 2008; Baayen, Davidson, & Bates, 2008; Baayen & Milin, 2010), assessing subject, item, and task effects jointly to obtain a more comprehensive picture of Japanese visual word recognition with 24 lexical variables, using 708 target words.

All previously mentioned studies relied on chronometric measures. In order to obtain more insight into the microstructure of information processing in lexical decision, we conducted an eye-tracking experiment combined with lexical decision. Previous studies (Hyönä & Pollatsek, 1998; Kuperman et al., 2008, 2009; Pollatsek et al., 2000) suggest that morphological processes can be investigated through eye-movements (but see Andrews, Miller, & Rayner, 2004, for lack of such strong link). Using a regression design with over 500 two-character words, we tested several questions in parallel. First, what is the time course of activation of strokes, radicals, characters, and words? Hierarchical models predict higher level units to become active only once their lower level constituent units have been activated. Hence, these models predict stroke effects to precede radical effects in the eye-movement record, radical effects to precede character effects, and character effects to precede whole word effects. The magnitude of the effects is also expected to vary with time. For instance, radical frequency is expected to have a large effect on initial fixation durations but little or no effect on later fixations. Of special interest here, given the early compound frequency effect observed in Kuperman et al. (2009), is the moment in time at which the effect of compound frequency first emerges.

Second, what is the relative importance of the left and the right characters in two-character word recognition? Does the left character have a privileged status compared to the right character, as argued by Hirose (1992)? If so, does an initial fixation on the right character have a catastrophic effect on comprehension? If, however, the right character is important, as suggested by Tamaoka and Hatsuzuka (1995) and Zhang and Peng (1992), it is worth considering whether the right character's privilege is due to a left-to-right scan process (Tamaoka & Hatsuzuka,

1995) or due to the fact that the right character is the main morpheme that should be processed first, at least in reading modifier-head compounds (Zhang & Peng, 1992). If a left-to-right scanning is preferred for Japanese, as for alphabetic languages (Hyönä & Pollatsek, 1998; Pollatsek et al., 2000), early and late time frames, as determined by eye fixations, should reflect the left and the right characters' contributions respectively.

Third, are semantic radicals interpreted semantically or do they function just as orthographic access codes? In the former case, we expect that the degree to which the semantic radicals contribute to the meaning of the character, as gauged by semantic transparency ratings (Feldman & Siok, 1999; Miwa et al., 2012), should co-determine fixation durations and/or lexical decision speed. If a semantic radical is interpreted semantically, then a next question would be whether a semantic transparency effect appears early, indicating early morpho-semantic processing (Diependaele et al., 2005, 2011; Feldman, O'Connor, & Moscoso del Prado Martín, 2009) or late, indicating that early morphological processing is semantically blind (Davis & Rastle, 2010; Longtin & Meunier, 2005; Longtin, Segui, & Halle, 2003; McCormick, Rastle, & Davis, 2008; McCormick, Rastle, & Davis, 2009). If an early semantic involvement in morphological processing is a must, then radical and character semantic transparencies should show facilitation in the earliest time frame.

Fourth, to what extent is the uptake of visual information co-determined by non-linguistic factors? We manipulated the readers' attention by varying the fixation point, which was positioned on the left character, on the right character, or in between the two characters. Kajii, Nazir, and Osaka (2001) report that fixations tend to fall onto the left character in sentential reading. However, the position of fixations seems to be more flexible (left or centre) in Chinese (Yan, Kliegl, Richter, Nuthmann, & Shu, 2010). Furthermore, if the right character is the main morpheme (Zhang & Peng, 1992), then an initial fixation on the right character may be more beneficial. Most previous isolated word reading studies directed the readers' attention to the word centre, which limits generalizability of the results. However, by shifting attention to other positions in the word, the consequences of dis-preferred initial fixation positions can be evaluated.

Predictors

In our study, we made use of a regression design with subjects and items as crossed random-effect factors. This section introduces the fixed-effect factors and covariates that we considered. Unless noted otherwise, we used lexical distributional data as available in the web-accessible database for Japanese characters constructed by Tamaoka et al. (2002) and Tamaoka and Makioka (2004). Table 1 summarizes the lexical distributional properties considered in the present study, grouped by different levels of linguistic structure posited by the hierarchical models as developed by Taft et al. (1999) and Saito (1997).

Insert Table 1 around here

Feature-level predictors

At the feature level, *LeftKanjiStrokes* and *RightKanjiStrokes* quantify the number of strokes in a character. The stroke count measure is designed to capture what word length captures for alphabetic languages: the complexity of the visual input. Word length generally has an inhibitory effect in chronometric and eye-tracking studies (Balota et al., 2004; Vitu, O'Regan, & Mittau, 1990), although there is some evidence for non-linearity for shorter word lengths (Baayen, 2005; New, Ferrand, Pallier, & Brysbaert, 2006). Similarly, previous studies on Japanese and Chinese suggest that characters with many strokes are processed slower than those with few strokes (Leong, Cheng, & Mulcahy, 1987; Liu, Shu, & Li, 2007). Note, however, that feature level complexity in Japanese manifests itself in the form of the density of visual information within a highly restricted fixed word region. As a consequence, the visual acuity limitation relevant for scanning extended strings of letters in alphabetic languages will not contribute to the visual complexity effects in Japanese.

Radical-level predictors

At the level of radicals, *LeftKanjiRadicalCombinability* and *RightKanjiRadicalCombinability* are the log-transformed type frequency of the semantic radicals, representing how many basic Japanese characters share a given semantic radical. *LeftKanjiRadicalTokenFreq* and *RightKanjiRadicalTokenFreq* are the log-transformed cumulative token frequency of all characters (in the 1,945 basic *kanji* list) sharing a given semantic radical, calculated from Amano and Kondo (2000). Previous studies (Feldman & Siok, 1997, 1999; Miwa et al., 2012; Taft & Zhu, 1997) suggest that we may expect facilitatory contributions from these type and token frequency measures. The present study considers only semantic radicals because all characters, regardless of their complexity, contain a semantic radical without exception whereas characters need not contain a phonetic radical.

Character-level predictors

At the level of characters, we considered log-transformed character token frequency (*LeftKanjiTokenFreq*, *RightKanjiTokenFreq*) and log-transformed position-dependent character neighbourhood size in two-character words (*LeftKanjiNeighbour* and *RightKanjiNeighbour*). Independent effects of constituent frequency and neighbourhood size in two-character word recognition have been reported by Tamaoka and Hatsuzuka (1995) and Kawakami (2002) respectively.

Word-level predictors

At the whole word level, we considered log-transformed written frequency (*WholeWordFreq*), based on newspapers published in the 14-year period from 1985 to 1998 in the lexical database of Amano and Kondo (2003) covering 341,771 words. We complemented this frequency measure with the log-transformed Google document frequency as of November 29, 2008. This dispersion measure provides an estimate of the range of different documents (genres, registers) in which a word is used. Contextual diversity of words has been reported as a powerful measure in some recent studies (e.g., Adelman, Brown, & Quesada, 2006; Brysbaert & New, 2009), and we expected this Google dispersion frequency to have an additive effect on top of the standard word frequency effect (see Ji & Gagné, 2007 and Myers, Huang, & Wang, 2006 for previous studies using Google document frequency).

Phonological predictors

In order to assess phonological ambiguity and its effect on reading (Ferrand &

Grainger, 2003; Pexman, Lupker, & Jared, 2001; Tamaoka, 2005), we made use of the log-transformed number of homophonous characters (*LeftKanjiHomophones* and *RightKanjiHomophones*). Tamaoka (2005) reported that words with a left character with many homophonic characters, relative to few, elicited longer response times in lexical decision and naming.[3]

Semantic predictors

Given the possibility of a processing advantage for semantically transparent compounds (Libben, 1998; Libben, Gibson, Yoon, & Sandra, 2003), we also included two measures for the semantic transparency of the characters in the compound. Although character activation in compound reading has been argued to be orthographic (Kawakami, 2002; Saito, 1997), other studies suggest that meanings of characters are co-activated (Tamaoka & Hatsuzuka, 1998; Ji & Gagné, 2007). *LeftKanjiTransparency* and *RightKanjiTransparency* gauge the semantic congruity between the meaning of the character and the meaning of the whole word. Both measures are based on mean ratings elicited from six native Japanese readers, using a seven-point scale (Cronbach's alpha > 0.99, *M* = 6.0, *SD* = 1.1 for *LeftKanjiTransparency*; Cronbach's alpha > 0.99, *M* = 6.0, *SD* = 1.0 for *RightKanjiTransparency*, using the *psy* package for R by Falissard, 2007). For example, 矛 'halberd' and 盾 'shield' in 矛盾 'contradiction' are relatively opaque with transparency ratings of 2 for both characters, while 空 'air' and 港 'port' in 空港 'airport' are relatively transparency with transparency ratings of 6 for both characters.

Furthermore, in order to test whether semantic radicals are mere orthographic access units or meaningful “orthographic morphemes”, we included two measures of semantic radical transparency (*LeftKanjiRadicalTransparency* and *RightKanjiRadicalTransparency*). These measures represent the degree of semantic congruity between the meaning of the character and the meaning of the radical. Eight native Japanese readers rated similarity in meaning between characters and their semantic radical on a seven-point scale ($M = 3.9$, $SD = 1.7$, Cronbach’s alpha > 0.99). In the analyses below, we used the mean ratings. For example, the semantic radical 火 ‘fire’ in 炊 ‘cook’ is relatively transparent (transparency rating = 6) while 氵 ‘water’ in 法 ‘law’ is opaque (transparency rating = 1).

Multicollinearity among lexical predictors

The present set of lexical distributional predictors is characterized by serious multicollinearity. We removed most of this collinearity by residualization of correlated predictors, following Kuperman et al. (2009). For example, because *WholeWordFreq* is highly correlated with *GoogleDocFreq* ($r = 0.59$, $p < 0.01$), we regressed the latter on the former and used the resulting residuals, *GoogleDocFreqResid*, as a new predictor gauging the Google document frequency uncontaminated by the written newspaper-based frequency. We followed the same procedure for other pairs of predictors that are highly correlated: *RightKanjiNeighbourResid* was orthogonalized with respect to *RightKanjiTokenFreq* ($r = 0.88$ for the correlation between *RightKanjiNeighbourResid* and *RightKanjiNeighbour*), *RightKanjiRadicalTokenFreqResid* was residualized on *RightKanjiRadicalCombinability* ($r = 0.48$), and *RightKanjiStrokesResid* was residualized on *RightKanjiNeighbour* ($r = 0.92$). Because the pattern of multicollinearity among lexical predictors was identical for characters at the left position, the same procedure was followed for computing residualized predictors. As a result, all pairwise correlations among the given lexical properties became less than 0.30, except that between *LeftKanjiTransparency* and *RightKanjiTransparency* ($r = 0.59$). As for these two predictors, we tested one predictor at a time in a given analysis. As we shall see below, one predictor always outperformed the other, so this correlation was not a problem (see Appendix A for a correlation matrix for all the numerical predictors considered in this study).

Individual differences and task-related predictors

Although the readers we tested in the present study were all native Japanese readers, they differed in the extent to which they are using Japanese in Canada. As a measure of language proficiency, we included their log-transformed *LengthOfStayCanada* in months as a predictor. This measure correlated positively with age ($r = 0.47$, $p = 0.03$) and negatively with log-transformed self-ratings of daily exposure to Japanese ($r = -0.52$, $p = 0.01$) and the 100-Rakan Japanese *kanji* reading ability scores (Kondo & Amano, 2001, $r = -0.54$, $p = 0.01$). *LengthOfStayCanada* did not correlate significantly with vocabulary size in Japanese (Amano, Kondo, & Kataoka, 2005) for the readers we tested. Vocabulary size in Japanese, however, correlated positively with 100-Rakan reading ability scores ($r = 0.46$, $p = 0.04$, cf., $r = 0.70$, $N = 1000$; Amano, 2007), which also correlated with *LengthOfStayCanada*. Given this multicollinearity, we opted for *LengthOfStayCanada* as the predictor reflecting various types of individual differences and language proficiency for our statistical analyses, leaving the specific advantages and disadvantages of the other related measures to future research.

Consistency in human behaviour often leads to auto-correlated time series of response times and fixation durations (Baayen & Milin, 2010; de Vaan, Schreuder, & Baayen, 2007; Kuperman et al, 2009; Perea & Carreiras, 2003). We removed the auto-correlation from the errors by including three control predictors: *PreviousRT*, the response time at the previous trial, *PreviousTrialCorrect*, a factor encoding the correctness of the response at the previous trial (levels *Correct* and *Incorrect*), and *Trial*, the rank of the item in the experimental list.

A further predictor was *Fixation*, a factor specifying whether the initial fixation was directed to the *Left* character, the *Central* position between the two characters, or the *Right* character.

In the eye-movement analyses, we considered *PreviousSubgazeDuration*, the subgaze duration at the previously fixated region, and *EyePosition*, a factor encoding the current eye position (levels *Left* and *Right* character regions).

Experiment 1: Lexical decision with eye-tracking

Method

Participants. Twenty-one native Japanese speakers (18 female, 3 males; mean age = 21.2 years old, *SD* = 2.9) were recruited at the University of Alberta. All participants had normal or corrected-to-normal vision, and their mean score on the 100-Rakan *kanji* word reading test was 48.7 out of 100 (*SD* = 19.9), which is comparable to the larger population mean (*M* = 49.6, *SD* = 19.6, *N* = 1000; Amano, 2007). The participants had been in Canada for 25.9 months on average (*SD* = 26.9, range 0 to 76 months).

Apparatus. An SR Research EyeLink II head-mounted eye-tracker was used to track participants' eye-movements. The pupil-only mode was used to track eye movement with a sampling rate of 250 Hz. Words were presented on a 20-inch display controlled by SR Research Experiment Builder.

Materials. Target words in this lexical decision experiment were randomly sampled from a subset of the NTT lexical database (Amano & Kondo, 2003). This subset was compiled from the database by imposing the following restrictions. First, the words should occur at least 100 times in the newspaper corpus. Second, only common nouns were selected. Third, the words with homophonous neighbors were excluded. Fourth, the words should not contain a duplicated character (e.g. *oriori* 折々 'occasional' where 々 indicates that the left character is repeated) nor a *kanji* numeral (e.g. *hachinin* 八人 'eight people'). Fifth, the words should not be restricted in their use to fixed or idiomatic phrases (e.g., *katabo* 片棒 'a bar' normally occurs in an idiom *katabo wo katsugu* 'take part in'). Sixth, relatively unfamiliar two-character words that are not listed in *Kojien Japanese Dictionary* (Nimura, 2002) were excluded as well (e.g., *konkaku* 混獲 'mass capturing'). From the resulting subset, we randomly sampled 708 two-character words.

We also prepared 708 nonwords falling into four different types: (1) 60 nonwords were created by switching the order of two characters, (2) 60 nonwords were created by replacing the first constituent with another homophonous character, (3) 60 nonwords were created by replacing the second constituent with another homophonous character, (4) the remaining 528 nonwords were created by randomly combining characters. The first three sets of nonwords were included as part of a separate study not reported here.

Procedure. The experiment consisted of three sessions conducted on different days. Each session lasted for approximately 90 minutes, except for the first session that lasted for 120 minutes. At the beginning of the first session, participants completed the 100-Rakan test and the vocabulary size estimation test.

In the lexical decision experiment, participants were asked to indicate whether the presented word is a legitimate Japanese two-character word or not by pressing buttons on a Microsoft SideWinder game pad with their left (= No) and right (= Yes) index fingers. Their eye-movements were tracked by an EyeLink II head-mounted eye-tracker. For each trial, a fixation point (an asterisk * in 60 point Verdana bold font), which was also used for drift correction, was presented for at least 500 ms, followed by a target two-character word in white Mincho font, size 130, on a black background. With a viewing distance of 70 cm from the screen, the visual angle was 5.3° for each character. The word remained on the screen until the participant responded. A drift correction was performed at every trial; a target word did not appear until participants had fixated on the fixation point. The location of the fixation point was varied across different sessions such that participants were presented with a fixation either at the central position of the screen, at a position slightly towards the left (i.e., where a left character was presented), or at a position slightly towards the right (i.e., where a right character was presented). The order of sessions with different fixation points was counter-balanced within subjects.

The lexical decision experiment started with 12 practice trials in each session, followed by 472 experimental trials ((708 + 708)/3) containing two breaks. After the practice trials and at each break point, participants were given feedback as to how fast (ms) and accurately (correct %) they had been responding so far. Throughout the entire experiment, the left eye was tracked for the half of the participants and the right eye was tracked for the rest of the participants. The words were presented in a different randomized order to each subject.

Results

Statistical analyses were carried out using R version 2.13.2 (R Development Core Team, 2011). Data from two participants were excluded from the subsequent RT and eye-movement analyses due to high error rates (exceeding 35%). All predictors with a skewed distribution (i.e., frequency-based predictors and the readers' length of stay in Canada) were logarithmically transformed.

As dependent variables, we considered response times (RTs), as well as first and second subgaze durations. Total fixation durations were virtually identical to response times and are not analyzed separately. Subgaze duration was defined as the cumulative first-pass fixation duration that fell into one character before the eye departed to another character. The onset of the first subgaze period on a target word began from the onset of the target word presentation. We opted for the subgaze duration based on character regions, as visual inspection of the on-line eye-movements and density plots for fixations suggested that the eye-movements were character-based and not radical-based. In trials with two and three fixations, 70% of the eye-movements moved to the other character region (71.3%, 65.3%, and 73.3% for the left, central, and right fixation conditions respectively).

Response time analysis. For the response time analysis, data points with response time shorter than 300 ms or longer than 3,000 ms were excluded from the dataset. In addition, all data points of those words that elicited over 40% incorrect responses were removed. Furthermore, remaining individual data points with an incorrect response were excluded as well. The analysis was restricted to those two-character words for which the lexical distributional properties were available for both the left and right characters. This resulted in a dataset with 9,228 data points for 555 different words. Because the distribution of RTs was highly skewed with a long right tail, a reciprocal transformation (-1000/RT) was applied to the RTs. Using a linear mixed-effects model with subject and word as crossed random-effect factors (Baayen, 2008; Baayen et al., 2008; Bates, Maechler, & Dai, 2007), we first fitted a simple main effects model with lexical properties at all levels of the hierarchy listed in Table 1.[4] We then considered interactions with respect to *Fixation*, *PreviousTrialCorrect*, and *LengthOfStayCanada*. After removing non-significant predictors to obtain the most parsimonious yet adequate model, we removed as potentially harmful outliers data points with standardized residuals exceeding 2.5 standard deviation units, and then refitted the model. The random effect structure of the final model comprised random intercepts for item ($SD = 0.12$) and subject ($SD = 0.21$), by-subject random slopes for centralized *Trial* ($SD = 0.01$), for centralized *PreviousRT* ($SD = 0.07$), and for *GoogleDocFreqResid* (SD = 0.01). Other random slopes were tested, and none were significant. The standard deviation of the residual error was 0.26. Table 2 summarizes the coefficients of this model and Figure 2 visualizes the interactions. Predictors that did not reach significance at the 5% level are not listed in Table 2.

Insert Table 2 and Figure 2 around here

Feature-level effects. Lexical distributional properties at all levels of the hierarchy emerged as significant predictors of the response times. Words with greater left character feature complexity (*LeftKanjiStrokesResid*) elicited longer response times (effect size = 101 ms). The absence of a significant effect of *RightKanjiStrokesResid* is consistent with theories that assume processing to proceed from left to right (Hirose, 1992; Taft & Zhu, 1997; Tamaoka & Hatsuzuka, 1995).

Character-level effects. The effect of *RightKanjiTokenFreq* was facilitatory, particularly when the response at the previous trial was incorrect (Figure 2, Panel a). We suspect that after readers make an error, they pay special attention to the head character, as this will help them to make a correct lexicality decision: In order to reject a stimulus such as *cloudchair*, the readers have to assess whether *cloudchair* is an existing kind of chair. If this interpretation is correct, the effect of *RightKanjiTokenFreq* is a late, conceptual, effect.

Word-level effects. *WholeWordFreq* and *GoogleDocFreqResid* both facilitated responses (effect sizes = -180 ms and -180 ms). The presence of the additive effect of *GoogleDocFreqResid* suggests a need to consider contextual diversity of words as an important factor in understanding how words are entrenched in memory (Adelman et al., 2006; Brysbaert & New, 2009). Adelman et al. (2006) reported for English that when frequency is residualized on contextual diversity, it is no longer a significant predictor. For the present data, this did not hold: Both residualized frequency and *GoogleDocFreq* contribute independently to the model, both $p < 0.0001$).

Phonological effects. The number of homophones of the right character slowed down responses as well (effect size = 53 ms), as expected. This finding contrasts with Tamaoka's (2005) observation of an inhibitory morphemic homophony effect for the left character only. This difference might be due to the way nonwords were constructed. In Tamaoka's (2005) study, nonwords were pseudo-homophones with homophonic left characters only. In the present study, the pseudo-homophones appeared in both positions, while in addition many nonwords were random combinations of characters. As a consequence, the role of the right constituent as the head is more important in the present study. This morphemic homophony effect may reflect a rebounding effect of phonology to orthography (Pexman et al., 2001; Tamaoka, 2005, 2007). Alternatively, it may reflect competition between different meanings associated with homophonic alternatives. We will return to the homophone effect below when discussing the second subgaze durations.

Semantic effects. The semantic transparency of the right character speeded up responses as the experiment went by (Figure 2, Panel b), suggesting that the criteria for discriminating between words and nonwords were adjusted in the course of the experiment. In this task, it is not trivial to discriminate real transparent compounds such as *handbag* from nonwords such as *toebag*. In the course of the experiment, the reader becomes more proficient at discriminating the words from the nonwords, apparently by relying more on the presence of a transparent semantic relation between the head and the modifier in memory, which is not available for nonwords. As a consequence, the expected facilitation from the head transparency emerges later in the experiment. These effects of the character transparency emerged only the reaction time analysis and were absent in the analyses of subgaze durations. This suggests that the effect occurs late, after the eye has completed extracting information from the individual characters.

Individual differences. Finally, individual differences were present (Figure 2, Panel c), notably for trials with the fixation mark placed at the central position. As can be seen in Panel c, the central fixation position elicited faster response times, suggesting that this central position is the optimal viewing position for isolated compound reading. For readers who have stayed longer in Canada, however, the advantage of this optimal viewing position became increasingly smaller. Recall that *LengthOfStayCanda* is correlated with other predictors (e.g., the amount of exposure to Japanese, age, and reading ability), hence a precise interpretation of this effect requires further research (cf. Goral et al., 2008, for dissociation of age and linguistic effects in lexical attrition). Table 2 also lists the contribution of *LeftKanjiNeighbourResid*: Response times decreased (effect size = -41 ms) with increasing *LeftKanjiNeighbourResid*. We discuss the interpretation of this effect below in the analyses of the subgaze durations.

First subgaze duration analysis. Only items and subjects analyzed in the response time analysis were considered for eye movement analyses. The number of fixations elicited varied from 1 to 15 per trial, with the mode at 3 fixations (3,203 trials), followed by 2 fixations (2,772 trials) and 4 fixations (1,348 trials). A small minority of 428 trials elicited only one fixation. In the subsequent analyses, we focused on subgaze durations. Subgaze counts varied from one to eight fixations with the mode at two subgazes. In the subsequent subgaze duration analyses, we focus on the trials with exactly two subgazes, which represent the large majority of data points (72% of the subgazes).[4]

For the analysis of the first subgaze durations (3,711 data points), initial fixations shorter than 100 ms were removed. In a quantile-quantile plot of the first subgaze durations, these short fixations patterned differently from the remaining durations. Trials that elicited incorrect responses for the lexical decision and trials with a blink were also excluded. The remaining durations were subsequently log-transformed to adjust for non-normality. The quantiles of raw first subgaze durations are 113 ms (minimum), 237 ms (1st quartile), 319 ms (median), 409 ms (3rd quartile), and 1080 ms (maximum).

Insert Table 3 and Figure 3 around here

We fitted a mixed-effects model with subjects and items as crossed random effect factors to the first subgaze durations. We considered all pairwise interactions and removed unsupported coefficients from the model specification. To safeguard against adverse effects of outliers, data points with absolute standardized residuals exceeding 2.5 were removed and the model was refitted. The coefficients of this model are summarized in Table 3, and the interactions are visualized in Figure 3. The random effect structure of this model comprised random intercepts for item (*SD* = 0.07) and subject (*SD* = 0.18), by-subject random slopes for *Trial* (*SD* = 0.0003), and by-subject random contrasts for *EyePosition* (*SD* = 0.37). The random contrasts for *EyePosition* capture the heteroscedasticity characterizing the two eye positions, with greater variance when the eye is fixating on the right character. The standard deviation of the residual error was 0.25.

Feature-level effects. As expected, feature-level complexity contributed substantially to the first subgaze durations. Character stroke complexity interacted with the location of the fixation (*EyePosition*) illustrated for *LeftKanjiStrokesResid* in Panel a and *RightKanjiStrokesResid* in Panel b. More complex characters elicited longer subgaze durations when the character was currently fixated on, but shorter subgaze durations when the character was not fixated on. This pattern resembles parafoveal-on-foveal effects as reported in sentence reading, with complexity and difficulty in the parafoveal region attracting attention and shortening the time the eye remains on the current constituent (Hyönä & Bertram, 2004; Kennedy & Pynte, 2005; Kliegl, Nuthmann, & Engbert, 2006; Pynte, Kennedy, & Ducrot, 2004). The processing of the non-fixated information unit indicates that the strict eye-mind assumption is too restrictive.

Radical-level effects. The type frequency of the characters' radicals, *LeftKanjiRadicalCombinability* and *RightKanjiRadicalCombinability*, was inhibitory for the left character (effect size = 24 ms) and facilitatory for the right character (effect size = -24 ms). The asymmetrical contributions of the left and the right radicals arose possibly because the semantic class marked by the modifier's radical was incompatible with that of the whole word (see also Miwa et al., 2012, for asymmetrical contribution of the left and the right radicals). In addition, *RightKanjiRadicalTokenFreqResid* co-determined the first subgaze durations but in an attention-dependent manner (Panel c): Its inhibitory contribution was evident only when the eye was on the right character. Note that although radical properties co-determined the first subgaze durations, the magnitudes of their effects were small or only *EyePosition*-specific.

Character-level effects. An effect of *LeftKanjiTokenFreq* was present in an interaction with *EyePosition* and *LeftKanjiNeighbourResid*, the type count of the number of two-character words sharing the left character. When the eye was fixating on the left character (Panel d), regardless of the number of the left kanji's neighbours, *LeftKanjiTokenFreq* speeded up recognition. When the eye was fixating on the right character, a cross-over interaction was observed (Panel e). Words with few *LeftKanjiNeighbourResid* showed facilitation from the left character's frequency. As the number of completions increased, this facilitation disappeared and reversed into inhibition. Panels (d) and (e) together illustrate a general preference for processing the left character regardless of the initial eye position. *LeftKanjiTokenFreq* therefore shows an expected facilitatory effect when the character is attended (Panel d).

In addition to the effect of *LeftKanjiTokenFreq*, an effect of *RightKanjiTokenFreq* was present but only in an interaction with *LeftKanjiNeighbourResid* (Panel f): When there are few possible completions on the right (low *LeftKanjiNeighbourResid*), facilitation by the right character's frequency was observed. However, in the presence of greater uncertainty about the identity of the right character in a dense neighbourhood, readers cannot utilize *RightKanjiTokenFreq*. This is in line with Hyönä, Bertram, and Pollatsek's (2004) report that the second constituent is processed more deeply when it is more constrained. In their sentential reading study with an eye-movement–contingent display change technique, the change effect associated with the second constituent was stronger for words with a first constituent with low frequency and small family size. The effect of *RightKanjiTokenFreq* for both eye positions is consistent with the previously discussed effect of parafoveal preprocessing of feature properties (Panels a and b).

Word-level effects. More frequent compounds elicited shorter first subgaze durations, as reflected by the negative coefficients of *GoogleDocFreqResid* (-26 ms), although *WholeWordFreq* was not significant. Such an early contribution of whole word frequency was also reported by Kuperman et al. (2009) for Dutch. As we shall see below, the effect of compound frequency became stronger at the second subgaze.

Phonological effects. Character phonology, *LeftKanjiHomophones* and *RightKanjiHomophones*, did not co-determine the first subgaze duration. This is consistent with the hypothesis that homophonic effects in visual word recognition are due to rebounding activation from phonology to orthography (Tamaoka, 2005; Pexman, Lupker, & Jared, 2001). If this line of reasoning is correct, we should be able to observe phonological effects at the second subgaze duration (see below).

Semantic effects. Furthermore, there was an inhibitory effect of *RightKanjiRadicalTransparency* (12 ms). If the radical is more transparent, it is more effective in activating its own typically more general meaning (e.g., 月 ‘body part’ in 脳 ‘brain’), which will compete with the meaning denoted by its character. Unlike in the analysis of response times, *LeftKanjiTransparency* and *RightKanjiTransparency*, both of which evaluate the semantic contribution of the character to the meaning of the two-character compound, did not reach significance for the first subgaze duration. Apparently, at the first subgaze, it is a local semantic relation, transparency of the radical and its character, that is available for processing.

Second subgaze duration analysis. 3,731 data points for the second subgaze durations in the trials with two subgazes were analyzed in a mixed-effects model with subjects and items as crossed random effect factors. A square root transformation was used to adjust non-normality in the distribution of the subgaze durations. The quantiles of raw second subgaze durations are 28 ms (minimum), 180 ms (1st quartile), 288 ms (median), 404 ms (3rd quartile), and 1196 ms (maximum).

The random effect structure of the final model comprised random intercepts for item (*SD* = 0.93) and subject (*SD* = 1.35), by-subject random slopes for centralized *Trial* (*SD* = 0.002), centralized *PreviousRT* (*SD* = 0.47), centralized *PreviousSubgazeDuration* (*SD* = 1.84), and by-subject random contrasts for *EyePosition* (*SD* = 2.18). The standard deviation of the residual error was 2.94. Table 4 lists the coefficients of the model and Figure 4 visualizes the interactions.

Insert Table 5 and Figure 4 around here

Feature-level effects. As can be seen in Figure 4, Panels a and b, the effects of character stroke complexity, *LeftKanjiStrokesResid* and *RightKanjiStrokesResid*, depended on the location of the eye fixation. The general patterns of these interactions are comparable to those observed for the first subgaze duration (Figure 3, Panels a and b). However, at this second subgaze, if the eye fixated on the left character, *LeftKanjiStrokesResid* greatly slowed down the second subgaze (the solid line, Figure 4, Panel a), while if the eye fixated on the right character, the effect of *LeftKanjiStrokesResid* was muted. The effects of *RightKanjiStrokesResid* showed a reversed pattern (Panel b). Interestingly, the effects of the two character stroke complexities are small when the eye rests on the right character, but large when the eye rests on the left character. This difference may be due to the preferential processing path from left to right. If the reader starts at the left, the second subgaze duration concerns the right character. At this point, a substantial amount of information is already available from the first character, smoothing the way for reading the second character. However, if the reader starts from the right character, then the second subgaze duration concerns the left character, the normal starting position for reading, and therefore inviting more in-depth processing of the left character.

Character-level effects. The contributions of *RightKanjiTokenFreq* (-52 ms) and *RightKanjiNeighbourResid* (-52 ms) are comparable to the corresponding effects of the left character at the first subgaze. Whereas *LeftKanjiTokenFreq* and *LeftKanjiNeighbourResid* contributed at the first subgaze, they did not reach significance at the second subgaze. This suggests that the weight of importance shifts from the left character to the right character in this later time frame.

Word-level effects. As expected, the effects of frequency and contextual diversity of the whole word, *WholeWordFreq* and *GoogleDocFreqResid*, became larger at the second subgaze (-69 ms and -82 ms respectively). As will be discussed below, *WholeWordFreq* interacted with *LeftKanjiRadicalTransparency.*

Phonological effects. Significant contributions of the numbers of homophonic characters were present for both the left and the right characters (*LeftKanjiHomophones* and *RightKanjiHomophones*, -29 ms and 56 ms respectively). Consistent with the analysis of response times (Table 2, 53 ms), *RightKanjiHomophones* was inhibitory. Furthermore, there was a smaller facilitatory effect of *LeftKanjiHomophones*, which contrasted with the inhibitory effect of *LeftKanjiHomophones* reported in Tamaoka's (2005) lexical decision study. This difference may be due to the different kinds of nonwords that we used, which included two-character words with illegal left characters. The late emergence of these homophone effects is consistent with the hypothesis that homophonic characters are activated only after the target character's phonological representation has been activated (rebounding activation; Tamaoka, 2005).

Semantic effects. The semantic congruity between the characters and their semantic radical, *LeftKanjiRadicalTransparency* co-determined the second subgaze durations (Figure 4, Panel c). The processing advantage for words with semantically transparent constituents is consistent with the results of Libben et al. (2003). However, facilitation was restricted to higher frequency words and disappeared for low frequency words. *LeftKanjiRadicalTransparency* facilitates the recognition only when *WholeWordFreq* is high. Conversely, the effect of *WholeWordFreq* was strongest for words with high *LeftKanjiRadicalTransparency*. This interaction suggests that whole word frequency effect is at least in part a semantic effect.

The kinds of the effects observed at the second subgaze are qualitatively similar to those observed for the lexical decision response times. Interestingly, however, not only the second but also the first subgaze durations correlated with the RTs ($r = 0.34$, $p < 0.0001$, for the first subgaze duration; $r = 0.51$, $p < 0.0001$ for the second subgaze duration) with comparable $ß$ in the regression analysis ($ß = 0.14$ and $ß = 0.16$ respectively).

Discussion

Overall, the analysis of the first gaze durations identified contributions of lexical distributional properties at all levels of the morphographic structural hierarchy shown in Table 1. Although whole word frequency, character frequency, and radical frequency all co-determined first subgaze durations, the magnitude of their contributions differed. Properties of characters contributed robustly to a larger extent than properties of radicals and properties of whole word units, as diagnosed by their feature complexity, frequency, or transparency. The large contributions of characters suggest that the characters, rather than radicals, are the dominant recognition units for two-character words. Importantly, the above effects were observed across all subjects because we carefully checked for random-effect slopes for subject for our predictors. The present findings are more consistent with the character-based models of two-character word recognition (Tamaoka & Hatsuzuka, 1998; Joyce, 2004). However, the presence of both whole word frequency and radical effects at the first subgaze indicates that models positing that lexical access would proceed by first accessing the character and only then accessing the radical and the whole word representation are too restrictive.

With regard to the relative importance of the left and the right constituents, the properties of the left character contributed more than those of the right character at the first subgaze. This suggests that it is more effective to parse two-character words from left to right, although when read from right to left, the properties of the right character come into play as well, albeit to a lesser extent.

Thus far, we have interpreted the second subgaze in the same way as the first subgaze duration. However, in trials with more than one subgaze, the last subgaze was interrupted by the button press, which terminated the trials. This raises the question of to what extent the second subgaze is interpretable as a measure of information extraction and lexical access. The response time and the second subgaze duration incorporate the time required for motor response planning and response execution, estimated to be on the order of magnitude of 200 ms by Schmidt (1982). Given that the mean lexical decision response time in trials with two subgazes was 653 ms, it is estimated that the lexical decision was finalized around 653 – 200 = 453 ms post stimulus onset, i.e., after the first subgaze ($M = 323$ ms) but well before the end of the second subgaze. Assuming that the response execution time is constant, apart from random execution noise, and independent from lexical properties, then only the intercept of the regression model for the second subgaze is affected.[5]

The larger contributions of character properties compared to radical properties, particularly during the early processing stages, indicate that two-character words are processed in a character-driven manner, rather than by strictly combinatorial processes. However, joint contributions of morphographic units at all levels of the linguistic structure suggest that the character-based model is not sufficient to fully capture the complexity of morphographic word recognition at its current state. With respect to relative importance of the left and the right characters, eye-tracking highlighted their contributions at early and late processing stages respectively. Although the right character contributes more prominently to lexical decision responses, this was not because the right character is the primary access unit but because it contributes late when lexical decisions are made. Furthermore, semantic transparency effects for radicals indicate that radicals are not mere orthographic components.

Finally, it was also notable that the magnitude and the direction of lexical effects were modulated by readers' locus of attention in a left-to-right preferred processing path such that lexical properties of the fixated and non-fixated characters showed asymmetrical joint contributions.

It might, however, be argued that the character-driven processes we observed were induced by the large inter-character space that goes hand in hand with the relatively large character font size. Similarly, the small whole word frequency effect observed during the early time frame might be merely due to visual acuity limitation. Bertram and Hyönä (2003) investigated an effect of word length on morphological processes in Finnish and suggested that a decompositional route dominates over a direct route when processing long compounds. If a direct route to the compound representation also exists in Japanese, a smaller font size may trigger a substantially larger whole compound frequency effect at the early stage.

In addition to the font size, it might also be argued that the small contributions of radicals during the early stage of lexical processing in Experiment 1 were due to the nature of the nonwords. The nonwords in Experiments 1 were random combinations of characters. Hence, readers would not have to zoom in on radicals to distinguish words from nonwords. We evaluated the font size and nonword type accounts in Experiment 2.

Experiment 2: Evaluation of the font size and nonword type accounts

In Experiment 2, we tested whether the pattern of lexical activation we observed in Experiment 1 generalizes to words presented in the more commonly used 40-sized fonts (visual angle = 1.64º). The 40-size font represents a typical font size used in previous isolated word lexical decision studies (e.g., 1.38º in Feldman & Siok, 1999; 1.6º in Miwa et al., 2012; 1.23º in Myers et al., 2006; 2.05º in Shen & Forster, 1999; 1.6º in Taft & Zhu, 1997; 2.78º in Zhou, Marslen-Wilson, Taft, & Shu, 1999, where that the viewing distance was assumed to be 70 cm unless reported otherwise). In Experiment 2, we also used nonwords containing a non-existing character, with the aim of forcing readers to pay closer attention to intra-character components. Under those circumstances, the effect of radicals may emerge more prominently. However, if reading Japanese two-character compounds is fundamentally character-driven, then this manipulation of the nonwords should not affect the main patterns of results.

Method

Participants. Twenty-one native Japanese readers (17 females, mean age = 23.3 years old, *SD* = 5.9) participated at the University of Alberta, Canada.

Materials. Two hundred words were sampled randomly from the set of words used in Experiment 1, equally across ten frequency-ordered bins. An equal number of nonwords were prepared by replacing either the left or the right character's intra-character component with an existing constituent to make a non-existing character. Half the nonwords contained a non-existing left character, and the other half contained a non-existing right character.

Procedure. The procedure was identical to that in Experiment 1, but words were presented in smaller 40-size font (visual angle for each character = 1.64º).

Results

Response time analysis. The data were trimmed, and the response times were transformed in the same way as in Experiment 1. A mixed-effects model was fitted to inversely transformed response times for 192 words (3,559 data points). In our final model, the random effect structure comprised random intercepts for item (SD = 0.10) and subject (SD = 0.18), and by-subject random slopes for centralized *Trial* (SD = 0.05) and *PreviousRT* (SD = 0.07). The standard deviation of the residual error was 0.25.

As fixed effects, we identified *WholeWordFreq* ($p < 0.0001$, effect size = -94 ms) and *GoogleDocFreqResid* ($p < 0.0001$, effect size = -153 ms) as dominant lexical effects. The left and the right characters contributed to a comparable extent: *LeftKanjiTokenFreq* (p < 0.0342, effect size = -33 ms) and *RightKanjiTokenFreq* ($p < 0.0185$, effect size = -40 ms). Importantly, although the task forced the readers to attend to the intra-character structure, only a *Trial*-dependent small effect of *LeftKanjiRadicalTransparency* was observed (effect size changed from -14 ms to 30 ms, as the experiment went by). *LengthOfStayCanada* did not have a significant main effect, as in Experiment 1 (see Appendix B for the full summary of the significant fixed effects).

First fixation duration analysis. For analyses of eye movements, data points excluded for the response time analysis were excluded here as well. Words were scanned with two fixations most of the time (10% for a single fixation, 65% for two fixations, 20% for three fixations, and 3% for four fixations), and fixation counts ranged from 1 to 6 (M = 2.2, SD = 0.7). Since two fixations constituted the majority of the trials, we analyzed first and second fixation durations in trials with exactly two fixations.[6]

As in Experiment 1, only the trials with a correct response that elicited two fixations were analyzed (192 words, 2,272 data points). Initial fixations shorter than 100 ms and longer than 800 ms were removed (5 data point). The quantiles of raw first fixation durations are 120 ms (minimum), 296 ms (1st quartile), 348 ms (median), 412 ms (3rd quartile), and 792 ms (maximum).

In our final model fitted to the log-transformed first fixation durations, the random effect structure comprised random intercepts for item (SD = 0.07) and subject (SD = 0.10). The standard deviation of the residual error was 0.17. The fixed effect structure comprised a small yet significant effect of *GoogleDocFreqResid* (p = 0.0023, effect size = -44 ms) and large contributions of the left character properties, such as *LeftKanjiTokenFreq* ($p < 0.0001$, effect size = -123 ms). Importantly for the purpose of Experiment 2, radical properties did not contribute prominently: the observed radical effect of *LeftKanjiRadicalCombinability* was small and inhibitory (p = 0.0047, effect size = 24 ms) and is comparable to its effect observed in the first subgaze duration analysis in Experiment 1. In Experiment 2, the right characters' properties contributed more prominently than Experiment 1. Interestingly, as in Experiment 1, the left character effects and the right character effects were asymmetrical, and the magnitudes of effects for the former were larger:

For example, *LeftKanjiStrokesResid* inhibited (p = 0.0001, effect size = 129 ms) while *RightKanjiStrokesResid* facilitated (p = 0.0001, effect size = -60 ms), and *LeftKanjiTokenFreq* facilitated (p = 0.0001, effect size = -123 ms) while *RightKanjiTokenFreq* inhibited (p = 0.0022, effect size = 39 ms). All of these effects replicated the findings in Experiment 1 (see Appendix B for the full summary of the significant fixed effects). When subgazes were analyzed, the character-driven processing pattern was still replicated.

Second fixation duration analysis. We fitted a mixed-effects model to the square-root-transformed second fixation durations in the subset of trials analyzed above. The quantiles of raw second fixation durations are 24 ms (minimum), 144 ms (1st quartile), 216 ms (median), 288 ms (3rd quartile), and 732 ms (maximum). In our final model, the random effect structure comprised random intercepts for item (SD = 0.66) and subject (SD = 1.20), and by-subject random slopes for centralized *Trial* (SD = 0.36). The standard deviation of the residual error was 2.25.

As fixed effects, as in Experiment 1, properties of the right character and the whole compound unit dominated: *WholeWordFreq* (p = 0.0001, effect size = -43 ms), *GoogleDocFreqResid* (p = 0.0001, effect size = -88 ms), *RightKanjiTokenFreq* (p = 0.0001, effect size = -49 ms). Left character frequency effects did not reach significance. Note that, at this later fixation, whole word effects are large in magnitude, and *RightKanjiTokenFreq* shows a standard facilitatory frequency effect. Interestingly, this later time frame was also co-determined by the *Trial*-dependent effect of *LeftKanjiRadicalTransparency*, as seen in the response time analysis (See Appendix B for the summary of all significant predictors).

Discussion

Experiment 2 largely replicates the main findings of Experiment 1. Even when words are presented in smaller-size font and together with different nonwords, the effects of character properties were more prominent than those of radicals properties during the early processing stages. Experiment 2 also replicates that a whole word frequency effect emerges already in the early time frame with small yet significant effects, and contributes more strongly in the later time frame. The small effect of the frequency of the whole word unit at the first fixation in Experiment 2 suggests that the small effect size associated with the early whole word frequency effect in Experiment 1 was not due to a visual acuity constraint, but is an essential characteristic of morphological processing in Japanese observable across all subjects (i.e., random slopes for subjects were not justified for a whole word frequency effect). Importantly, when the subset of data in Experiment 1 with the left fixation position was analyzed (185 words for each subject), the pattern of results remained unchanged, suggesting that the fixation position and statistical power did not contaminate the comparison between the two experiments. With respect to relationship between non-linguistic task demand and lexical processing, the above results are in line with Kaakinen and Hyönä (2010)'s eye-tracking sentential reading study with a manipulation of task demands. In their study, depending on whether the task was comprehension or proof-reading, readers adjusted eye movements already at the first fixation according to the given task demand, with regard to the landing position and the fixation duration. However, lexical effects were not modulated by the task demands during this early time frame, while they were in the later time frame proved by the gaze duration analysis. Experiment 2 of the present study similarly demonstrated that, even when the task requires attention to intra-character radical components and the font size motivates fewer eye movements, character-driven processing remains unaffected.

General discussion

In this visual lexical decision with eye-tracking study, we tested several hypotheses in parallel: namely, whether the processing of morphographic two-character words proceeds strictly from the smallest units to large units in a bottom-up combinatorial manner, whether the right character is quantitatively and qualitatively more important than the left character, whether semantic radicals are processed semantically, and how non-linguistic variables affect lexical processes.

First, we studied the temporal order in which a two-character word and its constituent characters and radicals are activated in the course of lexical access. During the earliest time frame, both in Experiment 1 and 2, we observed a larger effect of left character frequency than those of radical combinability and whole word frequency. The early emergence of a whole word frequency effect replicates the previous findings for Dutch and Finnish (Kuperman, Bertram, & Baayen, 2008; Kuperman et al., 2009). During the later time frame, the effect of the frequency of the left character disappeared and was replaced by a large effect of the frequency of the right character. The magnitude of the whole word frequency effect increased in this later time frame. The early large effects of character frequency in combination with a small effect of whole word frequency, as well as later predominant effects of right character and whole word frequency effects, were replicated when words were presented in smaller fonts and presented with different types of nonwords. This indicates that the present character-driven processing signature does not depend on font sizes nor nonword-induced task demand in lexical decision.

Second, we studied the different contributions of the left and the right characters to the lexical decision responses. On the basis of the lexical decision response times alone, using frequency as a diagnostic for access to lexical representations, one would have to conclude that the right character is more important than the left (Experiment 1) or both are equally important (Experiment 2). Interestingly, the eye-tracking record revealed clear and strong frequency effects of the left character in the early time frame and those of the right character in the later time frame. The early left character advantage is consistent with the Yan et al. (2006) study, in which fixation durations on target words were co-determined more by the left character than by the right character. This indicates that the right character advantage reflected in the response times arises not because the right character is the main morpheme to be processed first. Instead, response times predominantly reflect later processes (i.e., later information uptake and subsequent decision processes; cf., Tamaoka & Hatsuzuka, 1995).

The time-course of the left-then-right constituent activation observed in the present study is comparable to that in eye-tracking studies on alphabetic compound processing (Hyönä & Pollatsek, 1998; Kuperman et al., 2008; Pollatsek et al., 2000). It should be noted, however, that the two constituents do not simply facilitate processing at different points in time; We observed that one inhibited processing while the other was facilitatory in nature (see also Vergara-Martínez, Duñabeitia, Laka, & Carreiras, 2009, for qualitatively different EEG signatures between left and right constituents in Basque compound word reading).

Third, we were interested in the depth to which semantic radicals are processed. Slight yet significant contributions of semantic radical transparency were observed in both eye movement and response time analyses, providing further support for Feldman and Siok's (1997, 1999) and Miwa et al.'s (2012) claim that semantic radicals contribute to the semantic interpretation of words. An issue that should be considered in parallel is whether initial morphological decomposition is morpho-orthographic (Davis & Rastle, 2010; Longtin, Meunier, 2005; Longtin, Segui, & Halle, 2003; McCormick, Rastle, & Davis, 2008; McCormick, Rastle, & Davis, 2009; Rastle, Davis, Marslen-Wilson, & Tyler, 2000; Taft & Nguyen-Hoan, 2010) or morpho-semantic in nature (Diependaele et al., 2011; Diependaele, Sandra, & Grainger, 2005; Feldman, O'Connor, & Moscoso del Prado Martín, 2009). The early radical transparency effect observed in the earliest time frame in Experiment 1 indicates that a semantic effect may co-determine the early morphological process. However, the early radical transparency effect we observed was not facilitatory but inhibitory, suggesting that the processing of semantic radicals was not in harmony with normal comprehension. Moreover, the effect was not observed in Experiment 2. This indicates that the effect is only conditional in nature. Indeed, the subset analyses confirmed that the radical transparency effect reached significance when the eye was on the left character ($ß = 0.005$, $p = 0.1$) but not when the eye was on the right character ($ß = 0.024$, $p = 0.0075$). The results indicate that an early semantic involvement is not a must.

Fourth, by manipulating the location of the fixation point and tracking eye movements, for the first time as an isolated word reading study, we found effects of a locus of attention on lexical processing. Strong parafoveal-on-foveal effects emerged, with the sign and the magnitude of stroke complexity effects modulated by the fixation location. When the eye attends to one character first, it is attracted to the other character when that character is highly complex, indicating the need for allocating processing resources to the other character (Kliegl et al., 2006; Pynte et al., 2004; Hyönä & Bertram, 2004). As a consequence, the greater the complexity of the unfixated character, the shorter the eye rests on the fixated character. Font size and task demand manipulations left the above pattern unchanged. It should be noted, however, in addition to the perceptual parafoveal-on-foveal interpretation, that a lexical interpretation is also possible in the case of compound processing. That is, activation of the first character activates the second character in the lexicon, regardless of the perceptual information in the parafoveal region.

In what follows, we assess how well current models of morphological processing explain the temporal order and the magnitude of effects of whole word, character, and radical activation. The supra-lexical model of Giraudo and Grainger (2001) predicts the whole word to be activated before its constituents (i.e., strong effects of whole word frequency, weaker effects of character frequency, and the weakest effects of radicals in the earliest time frame). However, the time-course of activation that emerges from our data is one in which the character is activated first, followed by the activation of the whole word on one hand and the activation of radicals on the other: In the early time frame, strong character frequency effects pair with a small whole word frequency effect and small radical combinability effects, indicating an initial access to character representations and subsequent spreading activations to radical and whole word representations.

The multilevel interactive activation model proposed for Japanese by

Tamaoka and Hatsuzuka (1998) correctly predicts, in the earliest time frame, that whole word effects should be smaller than character effects. It also correctly predicts rebounding phonological effects, which appeared late in our data. However, in this interactive activation model, semantic radicals are not represented by separate nodes. Given that combinability and transparency of semantic radicals affect lexical processes, albeit with small effect sizes, nodes for semantic radicals need to be incorporated in the model architecture.

Adding radical nodes to the model of Tamaoka and Hatsuzuka (1998) leads to the interactive activation architecture proposed for Chinese by Taft and Zhu (1997) and Taft et al. (1999) and for Japanese by Saito (1997). These models predict a time-course of activation that is exactly the opposite of the time-course predicted by the supra-lexical model. Now, radicals are supposed to be activated before characters, and characters before whole words. This architecture, however, is challenged by our eye-tracking data in that, in the earliest processing stages, effects of characters dominate over those of radicals.

Within the general interactive activation approach to lexical processing in Japanese, our data suggest a modification of both the model of Tamaoka and Hatsuzuka (1998) on one hand and that of Saito (1997) on the other. The compromise presented in Figure 5 incorporates nodes for radicals, characters, and words as in the model of Saito (1997) but, unlike this model, it includes connections from the feature level that link up directly to the character level, by-passing the radical nodes. Consequently, radicals can be activated, either by receiving rebounding activation from the character level or by receiving activation from the feature level (the dotted line in Figure 5). Our current data do not allow us to estimate the relative importance of these two routes for activation of radicals. However, given that radical effects are not modulated by frequency of the characters nor by word frequency, processing of radicals proceeds independently, with character activation taking precedence at least in early processing stages. By including level-skipping links from features to characters, the model accounts for the fact the characters are the most prominent units from the earliest time frame onward: Characters receive more bottom-up support than radicals.

Insert Figure 5 around here

Interestingly, this level-skipping assumption we propose for Japanese is comparable to direct whole word activation routes assumed to function in parallel to sequential decompositional routes in recent morphological processing models for alphabetic languages (Diependaele et al., 2005, 2011; Kuperman et al., 2009; Pollatsek et al., 2000). Diependaele et al. (2005, 2011) observed facilitatory semantic transparency effects in masked priming. In order to account for this arguably early morpho-semantic processing, Diependaele et al. (2011) reason that direct whole word access routes should be assumed, although they do not claim that whole word representations are the primary processing units. The results in the present study indicate that characters are the dominant processing units, at least in the early processing stages. The character-driven processing model provides a more straightforward interpretation of the results than strictly bottom-up models. However, this does not totally preclude the obligatory radical-based recognition models for Japanese and Chinese, not to mention obligatory morpheme-based models for alphabetic languages. To arrive at a fair conclusion, evidence should be accumulated with respect to what different experimental techniques measure (e.g., priming, eye-tracking), what language-general morphemes are, and what different statistical techniques do (i.e., the issue of statistical power).

The question remains why character representations emerge as primary access units. Our hypothesis is that characters carry the greatest amount of information for a word's intended meaning, compared to radicals and compounds. Radicals occur in any positions (i.e., top, bottom, left, right). Furthermore, semantic radicals may or may not denote general semantic categories, and phonetic radicals similarly may or may not provide information about a character's pronunciation. As a consequence, they are unreliable cues to a word's meaning (e.g., the semantic radical 木 ‘wood’ is not a helpful cue for 極 ‘extreme’, and occur at the bottom 楽 or top 査 positions). Conversely, many two-character compounds are semantically at least partially transparent and compositional. The greater their compositionality, the more the burden of interpretation rests with the characters. In other words, characters may be the most important cues to meaning, compared to radicals (which are ambiguous and less useful cues) and compared to whole words (due to compositionality). We leave the validation of this hypothesis, for instance within the naive discrimination learning framework proposed by Baayen et al. (2011) to future research.

In addition to the level-skipping assumption, there are two other differences between the architecture proposed in Figure 5 and the models proposed in the literature. First, we take semantic radicals to be the smallest meaningful units in the identification system; in other words, we consider semantic radicals to be orthographic morphemes. In Figure 5, semantic radicals therefore have out-going connections that link up to the semantic representations. These links are motivated by the significant radical transparency effect observed in our data, consistent with the results of Feldman and Siok (1997, 1999) and Miwa et al. (2012). Although radical morphemes, unlike morphemes in alphabetic languages, do not function as primary recognition units, they nevertheless contribute to a word's meaning percept.

Second, Figure 5 makes it explicit that task demands and decision making strategies co-determine responses and potentially affect lexical processing at later processing stages. In Experiment 1, the effect of the accuracy on the previous trial, in interaction with right character frequency, on the RTs indicates changes in local response criteria, while the interaction between trial and right character transparency is indicative of changes in global response criteria. These interactions involving lexical distributional predictors indicate that the two systems are not strictly staged but function in parallel at least at later processing stages. This assumption of late involvement of the non-linguistic system is based on that in the Bilingual Interactive Activation (BIA+) model (Dijkstra & van Heuven, 2002), which makes it explicit that bilinguals cannot suppress activation of two languages even when activation of one language is sufficient for completion of a given task.

With regard to lexical predictors to be considered for the visual recognition of Japanese morphographic words, we are fully aware that the present study considered only 18 lexical variables and that it remains important to extend the range of predictors to include, for instance, imageability (e.g., Balota et al., 2004; McMullen & Bryden, 1987), visuoperceptual features and geometrical complexity (Grainger, Rey, & Dufau, 2008; Huang & Wang, 1992), collocational N-gram frequency (Arnon & Snider, 2010; Tremblay, Derwing, Libben, & Westbury, 2011), and whether a compound is endocentric (and right-headed) or exocentric (see Joyce, 2002 for consideration of compound formation principles).

The experimental design requires consideration as well. The purpose of the present study was primarily to extend previous isolated word reading studies and test existing models of isolated word reading, rather than making a claim regarding what readers do in sentential reading. To this end, the present study examined eye movements simply as the means to infer cognitive processes, as in Kuperman et al. (2009). Although isolated word reading and sentential reading lead to a comparable processing architecture in Kuperman et al. (2008, 2009), it should yet to be tested whether this is the case for Japanese and Chinese, as sentential reading involves extra complexities (e.g., parafovel preview before fixating on a target word). For example, our isolated word reading study did not identify interaction between character and word frequencies reported in Yan et al.'s (2006) sentential reading study.[7]

Future research should also assess potential effects of individual differences on lexical access (see Andrews & Lo, 2011; Kuperman & Van Dyke, 2011; Yap, Balota, Sibley, & Ratcliff, 2011). Because we carefully checked for random-effect slopes for subject for our predictors, the main effects reported in the present study are very unlikely to be due to individual differences. Furthermore, our models can be used to extrapolate to domestic Japanese readers by setting the value of *LengthOfStayCanada* slightly below zero, in order to predict their expected response times. As the effects of *LengthOfStayCanada* are small, no major differences for domestic readers are anticipated. We leave it to future research to disentangle the precise contributions of length of stay, age, daily exposure to the language, and reading ability.

In conclusion, the present study documents processing consequences from all levels of morphographic structure, namely the radicals, the character, and the whole word. Eye-movements revealed that two-character words in Japanese are preferentially processed from the left character to the right character, with whole word frequency exerting an effect already from the earliest time frame. Importantly, the effects of character properties were robust and larger in magnitude than those of radicals and whole word properties at early processing stages. The patterns observed in all data combined led us to propose a character-driven architecture with a level-skipping assumption: Connections from the feature level by-pass the lower radical level and link up directly to the higher character level, allowing character effects to dominate early processing stages irrespective of font sizes and task demands.

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Appendix A.

A correlation matrix among numerical predictors considered in this study. Predictors with the superscript ^{R} were end-products of a residualization procedure. The significant correlations at the 0.01 level are bolded.

Predictors	1	1^{R}	2	2^{R}	3	4	5	5^{R}	6	6^{R}
1. LeftKanjiStrokes	**1.00**	**0.95**	0.00	-0.01	**0.16**	-0.02	-0.01	**-0.15**	-0.03	-0.02
1^{R}. LeftKanjiStrokesResid		**1.00**	0.00	-0.01	**0.14**	-0.03	0.01	**-0.16**	-0.04	-0.03
2. RightKanjiStrokes			**1.00**	**0.92**	0.04	0.09	0.04	-0.03	-0.03	-0.09
2^{R}. RightKanjiStrokesResid				**1.00**	0.04	0.04	0.05	-0.02	-0.05	**-0.14**
3. LeftKanjiRadicalCombinability					**1.00**	-0.04	**0.85**	0.00	-0.05	-0.04
4. RightKanjiRadicalCombinability						**1.00**	-0.02	0.02	**0.84**	0.00
5. LeftKanjiRadicalTokenFreq							**1.00**	**0.47**	-0.01	0.00
5^{R}. LeftKanjiRadicalTokenFreqResid								**1.00**	0.06	0.07
6. RightKanjiRadicalTokenFreq									**1.00**	**0.48**
6^{R}. RightKanjiRadicalTokenFreqResid										**1.00**
7. LeftKanjiNeighbour										
7^{R}. LeftKanjiNeighbourResid										
8. RightKanjiNeighbour										
8^{R}. RightKanjiNeighbourResid										
9. LeftKanjiTokenFreq										
10. RightKanjiTokenFreq										
11. WholeWordFreq										
12. GoogleDocFreq										
12^{R}. GoogleDocFreqResid										
13. LeftKanjiHomophones										
14. RightKanjiHomophones										
15. LeftKanjiRadicalTransparency										
16. RightKanjiRadicalTransparency										
17. LeftKanjiTransparency										
18. RightKanjiTransparency										

Predictors	7	7^{R}	8	8^{R}	9	10	11	12	12^{R}	13
1. LeftKanjiStrokes	**-0.31**	**-0.17**	-0.03	-0.03	**-0.31**	-0.01	-0.01	-0.04	-0.04	0.00
1^{R}. LeftKanjiStrokesResid	0.00	0.09	-0.03	-0.03	**-0.15**	-0.01	-0.01	-0.03	-0.04	-0.05
2. RightKanjiStrokes	0.01	-0.05	**-0.38**	**-0.30**	0.09	**-0.26**	-0.04	-0.03	-0.01	-0.06
2^{R}. RightKanjiStrokesResid	0.00	-0.05	0.00	0.04	0.08	-0.08	-0.04	-0.03	0.00	-0.05
3. LeftKanjiRadicalCombinability	-0.09	-0.01	0.00	0.01	**-0.15**	0.00	-0.01	-0.07	-0.07	-0.06
4. RightKanjiRadicalCombinability	-0.03	-0.05	**-0.15**	-0.10	0.01	**-0.13**	-0.04	-0.03	0.00	0.04
5. LeftKanjiRadicalTokenFreq	0.05	-0.02	0.00	-0.01	**0.12**	0.04	0.04	-0.03	-0.07	-0.04
5^{R}. LeftKanjiRadicalTokenFreqResid	-0.01	-0.01	0.02	0.01	0.00	0.03	-0.01	-0.04	-0.04	0.03
6. RightKanjiRadicalTokenFreq	-0.03	-0.06	-0.06	**-0.14**	0.03	**0.13**	0.04	0.02	0.00	0.03
6^{R}. RightKanjiRadicalTokenFreqResid	-0.01	-0.02	-0.09	**-0.11**	0.01	0.00	0.02	0.02	0.01	0.00
7. LeftKanjiNeighbour	**1.00**	**0.85**	-0.01	-0.02	**0.53**	0.01	0.00	0.02	0.03	**-0.15**
7^{R}. LeftKanjiNeighbourResid		**1.00**	0.01	0.04	0.00	-0.04	**-0.14**	-0.08	0.00	**-0.18**
8. RightKanjiNeighbour			**1.00**	**0.88**	-0.04	**0.48**	0.01	0.03	0.02	0.04
8^{R}. RightKanjiNeighbourResid				**1.00**	-0.09	0.00	**-0.13**	-0.04	0.05	0.07
9. LeftKanjiTokenFreq					**1.00**	0.09	**0.23**	**0.17**	0.04	0.00
10. RightKanjiTokenFreq						**1.00**	**0.26**	**0.13**	-0.03	-0.03
11. WholeWordFreq							**1.00**	**0.59**	0.00	0.03

12. GoogleDocFreq	**1.00**	**0.81**	0.02
12^{R}. GoogleDocFreqResid		**1.00**	0.00
13. LeftKanjiHomophones			**1.00**
14. RightKanjiHomophones			
15. LeftKanjiRadicalTransparency			
16. RightKanjiRadicalTransparency			
17. LeftKanjiTransparency			
18. RightKanjiTransparency			

Predictors	14	15	16	17	18
1. LeftKanjiStrokes	-0.07	**-0.19**	0.02	0.08	0.07
1^{R}. LeftKanjiStrokesResid	-0.06	**-0.12**	-0.01	0.07	0.07
2. RightKanjiStrokes	0.02	-0.08	**-0.20**	0.02	-0.01
2^{R}. RightKanjiStrokesResid	0.01	-0.07	**-0.12**	0.04	0.01
3. LeftKanjiRadicalCombinability	0.01	-0.03	-0.05	0.07	0.08
4. RightKanjiRadicalCombinability	0.04	-0.04	0.07	-0.02	0.03
5. LeftKanjiRadicalTokenFreq	0.01	-0.07	-0.07	0.08	0.09
5^{R}. LeftKanjiRadicalTokenFreqResid	0.03	-0.07	-0.03	-0.01	0.02
6. RightKanjiRadicalTokenFreq	0.07	-0.07	0.01	-0.02	0.03
6^{R}. RightKanjiRadicalTokenFreqResid	0.03	-0.01	**-0.11**	-0.05	-0.03
7. LeftKanjiNeighbour	0.05	**0.27**	-0.09	-0.03	-0.04
7^{R}. LeftKanjiNeighbourResid	0.09	**0.34**	-0.07	-0.09	-0.05
8. RightKanjiNeighbour	-0.02	0.04	**0.23**	0.05	0.05
8^{R}. RightKanjiNeighbourResid	-0.06	**0.10**	**0.26**	0.01	0.01
9. LeftKanjiTokenFreq	-0.05	-0.03	-0.06	0.08	0.02
10. RightKanjiTokenFreq	0.07	-0.10	0.01	0.08	0.09
11. WholeWordFreq	-0.04	**-0.13**	-0.05	0.03	0.02
12. GoogleDocFreq	-0.09	-0.06	-0.01	0.03	-0.03
12^{R}. GoogleDocFreqResid	-0.08	0.02	0.03	0.02	-0.06
13. LeftKanjiHomophones	**-0.16**	-0.07	-0.01	0.07	0.04
14. RightKanjiHomophones	**1.00**	0.05	0.05	-0.09	**-0.14**
15. LeftKanjiRadicalTransparency		**1.00**	0.04	-0.10	-0.09
16. RightKanjiRadicalTransparency			**1.00**	-0.01	0.07
17. LeftKanjiTransparency				**1.00**	**0.51**
18. RightKanjiTransparency					**1.00**

Appendix B.

Estimate, standard error, t-value, p-value, and effect size of influential predictors for the response times, first fixation durations, and second fixation durations for trials with two fixations in Experiment 2.

Response time	Type	Estimate	Std.Error	t-value	p-value	Effect size (ms)
(Intercept)		-1.122	0.101	-11.12	< 0.0001	
PreviousRT	Task	0.125	0.022	5.80	< 0.0001	119
Trial	Task	-0.082	0.015	-5.42	< 0.0001	-84
PreviousTrialCorrect (Incorrect)	Task	0.086	0.016	5.42	< 0.0001	30
LeftKanjiStrokesResid	Feature	0.007	0.002	3.25	0.0012	44
LeftKanjiTokenFreq	Character	-0.012	0.006	-2.12	0.0342	-33
LeftKanjiNeighbourResid	Character	-0.025	0.010	-2.48	0.0133	-40
RightKanjiTokenFreq	Character	-0.014	0.006	-2.36	0.0185	-40
WholeWordFreq	Word	-0.044	0.007	-6.39	< 0.0001	-94
GoogleDocFreqResid	Word	-0.059	0.007	-8.45	< 0.0001	-153
LeftKanjiHomophones	Phonology	-0.024	0.010	-2.25	0.0244	-32
LeftKanjiRadicalTransparency	Semantics	0.006	0.005	1.06	0.2874	11
LeftKanjiRadicalTransparency x Trial	Semantics x Task	0.006	0.002	2.79	0.0053	-14: 30
First fixation duration	**Type**	**Estimate**	**Std.Error**	**t-value**	**p-value**	**Effect size (ms)**
(Intercept)		6.076	0.072	84.08	< 0.0001	
LeftKanjiStrokesResid	Feature	0.019	0.002	11.19	< 0.0001	129
RightKanjiStrokesResid	Feature	-0.009	0.002	-4.37	< 0.0001	-60
LeftKanjiRadicalCombinability	Radical	0.017	0.006	2.83	0.0047	24
LeftKanjiTokenFreq	Character	-0.037	0.004	-8.42	< 0.0001	-123
LeftKanjiNeighbourResid	Character	-0.027	0.007	-3.81	0.0001	-45
RightKanjiTokenFreq	Character	0.013	0.004	3.07	0.0022	39
RightKanjiNeighbourResid	Character	0.019	0.007	2.85	0.0044	36
GoogleDocFreqResid	Word	-0.016	0.005	-3.05	0.0023	-44
Second fixation duration	**Type**	**Estimate**	**Std.Error**	**t-value**	**p-value**	**Effect size (ms)**
(Intercept)		75.148	1.545	48.64	< 0.0001	
PreviousFixationDuration	Task	-9.391	0.234	-40.18	< 0.0001	-872
PreviousRT	Task	0.807	0.152	5.31	< 0.0001	66
Trial	Task	-0.585	0.134	-4.37	< 0.0001	-49
PreviousTrialCorrect (Incorrect)	Task	0.682	0.184	3.70	0.0002	20
RightKanjiTokenFreq	Character	-0.192	0.047	-4.03	0.0001	-49
WholeWordFreq	Word	-0.219	0.053	-4.12	< 0.0001	-43
GoogleDocFreqResid	Word	-0.382	0.057	-6.68	< 0.0001	-88
LeftKanjiHomophones	Phonology	-0.228	0.084	-2.73	0.0064	-28
LeftKanjiRadicalTransparency	Sematics	0.040	0.041	0.98	0.3274	8
LeftKanjiRadicalTransparency x Trial	Semantics x Trial	0.053	0.025	2.13	0.0336	-12: 23

Footnotes

[1] With respect to two-character compounds, Japanese morphology has been argued to be predominantly right-headed (Kageyama, 2010), although exocentric compounds such as voyage ('ship' + 'sea') seem to occur more often than in English or Dutch.

[2] Although Kawakami interpreted this type count as a measure of orthographic neighbourhood density (cf., Coltheart, Davelaar, Janasson, & Besner, 1977; Forster & Taft, 1994), it can also be viewed as a measure of morphological family size (Bertram, Baayen, & Schreuder, 2000; Joyce & Ohta, 2002; Moscoso del Prado Martín et al., 2004; Schreuder & Baayen, 1997).

[3] In Japanese, characters may have two kinds of pronunciations: *ku* (*On*-Reading, Chinese origin) and *sora* (*Kun*-Reading, Japanese origin). In the context of *kuko* 空港 'airport', the On-Reading is applied, while in the context of *sorairo* 空色 'sky blue', the Kun-Reading is applied. Given that visual lexical decisions are based to a larger extent on orthographic and semantic properties of words, as well as that On-Kun status is finalized only after the whole word is activated, the effect of On-Kun distinction is expected to be small or null in the present study. This was indeed the case in the present study. Hence, this predictor is not mentioned in this paper.

[4] The analysis of the subgaze counts indicates that this subset is biased slightly towards words preceded by trials with a short response latency, words responded to by readers who had only recently left Japan, words with fewer strokes, and words with higher frequencies.

[5] The assumption that response planning and execution time is constant and does not vary with lexical properties may involve a simplification. For instance, Abrams and Balota (1991) observed that word frequency affects not only the timing but also the force with which the response is executed. As we asked our participants to keep their fingers on the response buttons during the experiment, the consequences of the differences in the force with which lexical decisions may have been executed for the estimates of the lexical decision speed and second subgaze durations are negligible.

[6] The analysis of the fixation counts indicates that this subset is biased slightly towards words preceded by trials with a short response latency, words presented later in the experiment, words with fewer strokes, and words with higher whole word and right character frequencies.

[7] The difference could be due to the task factor but also to a statistical aspect. That is, the latter study used matching, and only six words were studied in each of the eight conditions. As in any studies with matching followed by a fixed-effects model, it is not certain whether the effects are generalizable to all words beyond these specific stimuli.

Table 1

Lexical predictors, individual differences, and task effects considered in this study

Type	Predictors	
Feature (、、✓)	· LeftKanjiStrokesResid	· RightKanjiStrokesResid
Radical (氵)	· LeftKanjiRadicalCombinability · LeftKanjiRadicalTokenFreqResid	· RightKanjiRadicalCombinability · RightKanjiRadicalTokenFreqResid
Character (港)	· LeftKanjiNeighbourResid · LeftKanjiTokenFreq	· RightKanjiNeighbourResid · RightKanjiTokenFreq
Word (空港)	· WholeWordFreq	· GoogleDocFreqResid
Phonology	· LeftKanjiHomophones	· RightKanjiHomophones
Semantics	· LeftKanjiRadicalTransparency · LeftKanjiTransparency	· RightKanjiRadicalTransparency · RightKanjiTransparency
Individual	· LengthOfStayCanada	
Task	· PreviousRT · PreviousTrialCorrect · PreviousSubgazeDuration	· Trial · Fixation · EyePosition

Table 2

Estimate, standard error, t-value, p-value, and effect size of influential predictors for the lexical decision response times.

	Type	Estimate	Std.Error	t-value	p-value	Effect size (ms)
(Intercept)		-1.065	0.128	-8.29	< 0.0001	
PreviousRT	Task	0.140	0.018	7.88	< 0.0001	180
Trial	Task	-0.010	0.005	-2.01	0.0445	-156
Fixation (Left)	Task	0.083	0.022	3.79	0.0002	3
Fixation (Right)	Task	0.099	0.020	4.86	< 0.0001	15
PreviousTrialCorrect (Incorrect)	Task	0.189	0.055	3.43	0.0006	5
LengthOfStayCanada	Individual	0.058	0.039	1.47	0.1408	125
LeftKanjiStrokesResid	Feature	0.010	0.002	6.11	< 0.0001	101
LeftKanjiNeighbourResid	Character	-0.015	0.006	-2.61	0.0092	-41
RightKanjiTokenFreq	Character	-0.009	0.004	-2.16	0.0305	-36
WholeWordFreq	Word	-0.057	0.004	-13.28	< 0.0001	-180
GoogleDocFreqResid	Word	-0.052	0.006	-8.69	< 0.0001	-180
RightKanjiHomophones	Phonology	0.026	0.007	3.64	0.0003	53
RightKanjiTransparency	Semantics	-0.009	0.006	-1.59	0.1116	-28
RightKanjiTokenFreq x PreviousTrialCorrect (Incorrect)	Character x Task	-0.018	0.005	-3.59	0.0003	Figure 2 (a)
RightKanjiTransparency x Task	Semantics x Task	-0.002	0.001	-2.69	0.0072	Figure 2 (b)
LengthOfStayCanada x Fixation (Left)	Individual x Task	-0.027	0.008	-3.57	0.0004	Figure 2 (c)
LengthOfStayCanada x Fixation (Right)	Individual x Task	-0.032	0.007	-4.65	< 0.0001	Figure 2 (c)

Table 3

Estimate, standard error, t-value, p-value, and effect size of influential predictors for the first subgaze durations for trials with two subgazes.

	Type	Estimate	Std.Error	t-value	p-value	Effect Size (ms)
(Intercept)		6.196	0.079	78.49	< 0.0001	
Trial	Task	0.000	0.000	-2.00	0.0454	-63
PreviousRT	Task	0.043	0.013	3.37	0.0007	39
EyePosition (Right)	Task	-0.882	0.140	-6.30	< 0.0001	-92
LeftKanjiStrokesResid	Feature	0.019	0.002	12.11	< 0.0001	128
RightKanjiStrokesResid	Feature	-0.009	0.002	-5.55	< 0.0001	-57
LeftKanjiRadicalCombinability	Radical	0.019	0.005	3.91	0.0001	24
RightKanjiRadicalCombinability	Radical	-0.019	0.005	-3.72	0.0002	-24
RightKanjiRadicalTokenFreqResid	Radical	0.002	0.010	0.25	0.8021	3
LeftKanjiTokenFreq	Character	-0.038	0.004	-9.42	< 0.0001	-114
LeftKanjiNeighbourResid	Character	-0.139	0.055	-2.50	0.0124	-53
RightKanjiTokenFreq	Character	0.004	0.004	1.00	0.3176	14
GoogleDocFreqResid	Word	-0.012	0.005	-2.45	0.0142	-26
RightKanjiRadicalTransparency	Semantics	0.006	0.003	2.14	0.0328	12
LeftKanjiStrokesResid x EyePosition (Right)	Feature x Task	-0.045	0.004	-11.18	< 0.0001	Figure 3 (a)
RightKanjiStrokesResid x EyePosition (Right)	Feature x Task	0.024	0.004	5.54	< 0.0001	Figure 3 (b)
RightKanjiRadicalTokenFreqResid x EyePosition (Right)	Radical x Task	0.073	0.028	2.64	0.0083	Figure 3 (c)
LeftKanjiNeighbourResid x LeftKanjiTokenFreq	Character x Character	0.000	0.004	0.11	0.9130	Figure 3 (d e)
LeftKanjiNeighbourResid x EyePosition (Right)	Character x Task	-0.247	0.110	-2.24	0.0249	Figure 3 (d e)
LeftKanjiTokenFreq x EyePosition (Right)	Character x Task	0.045	0.010	4.56	< 0.0001	Figure 3 (d e)
LeftKanjiNeighbourResid x LeftKanjiTokenFreq x EyePosition (Right)	Character x Character x Task	0.030	0.010	2.98	0.0029	Figure 3 (d e)
LeftKanjiNeighbourResid x RightKanjiTokenFreq	Character x Character	0.009	0.003	2.73	0.0064	Figure 3 (f)

Table 4

Estimate, standard error, t-value, p-value, and effect size of influential predictors for the second subgaze durations for trials with two subgazes.

	Type	Estimate	Std.Error	t-value	p-value	Effect size (ms)
(Intercept)		19.921	0.934	21.33	< 0.0001	
PreviousSubgazeDuration	Task	-5.472	0.455	-12.02	< 0.0001	-1052
PreviousRT	Task	0.967	0.190	5.10	< 0.0001	92
Trial	Task	0.000	0.001	-0.42	0.6748	-11
EyePosition (Right)	Task	-0.155	0.549	-0.28	0.7781	-1
LeftKanjiStrokesResid	Feature	0.146	0.042	3.44	0.0006	102
RightKanjiStrokesResid	Feature	-0.089	0.046	-1.95	0.0516	-59
RightKanjiTokenFreq	Character	-0.190	0.046	-4.11	< 0.0001	-52
RightKanjiNeighbourResid	Character	-0.273	0.067	-4.11	< 0.0001	-52
WholeWordFreq	Word	-0.101	0.104	-0.97	0.3320	-69
GoogleDocFreqResid	Word	-0.345	0.057	-6.05	< 0.0001	-82
LeftKanjiHomophones	Phonology	-0.207	0.077	-2.69	0.0072	-29
RightKanjiHomophones	Phonology	0.404	0.079	5.13	< 0.0001	56
LeftKanjiRadicalTransparency	Semantics	0.365	0.170	2.15	0.0314	8
LeftKanjiStrokesResid x EyePosition (Right)	Feature x Task	-0.184	0.044	-4.20	< 0.0001	Figure 4 (a)
RightKanjiStrokesResid x EyePosition (Right)	Feature x Task	0.156	0.047	3.32	0.0009	Figure 4 (b)
LeftKanjiRadicalTransparency x WholeWordFreq	Semantics x Word	-0.060	0.025	-2.45	0.0143	Figure 4 (c)

Figure Captions

Figure 1 Radical-based and character-based multilevel models of morphographic word recognition, summarizing representations and links proposed by Taft, Zhu, and Peng (1999), Saito (1997), and Tamaoka and Hatsuzuka (1998). Activation of neighboring words and characters are not depicted in the figures. Lemma representations in Tamaoka and Hatsuzuka’s (1998) model are not shown in the character-based model depicted here (left).

Figure 2 Interactions co-determining the lexical decision response times and the number of subgazes

Figure 3 Interactions co-determining the first subgaze durations in trials with two subgazes

Figure 4 Interactions co-determining the second subgaze durations in trials with two subgazes

Figure 5 A character-driven processing model of Japanese two-character word recognition with semantic radicals as orthographic morphemes. The activations of morphographic neighbours, phonological neighbours, and semantic associates are not specified in the figure.

Figure 1

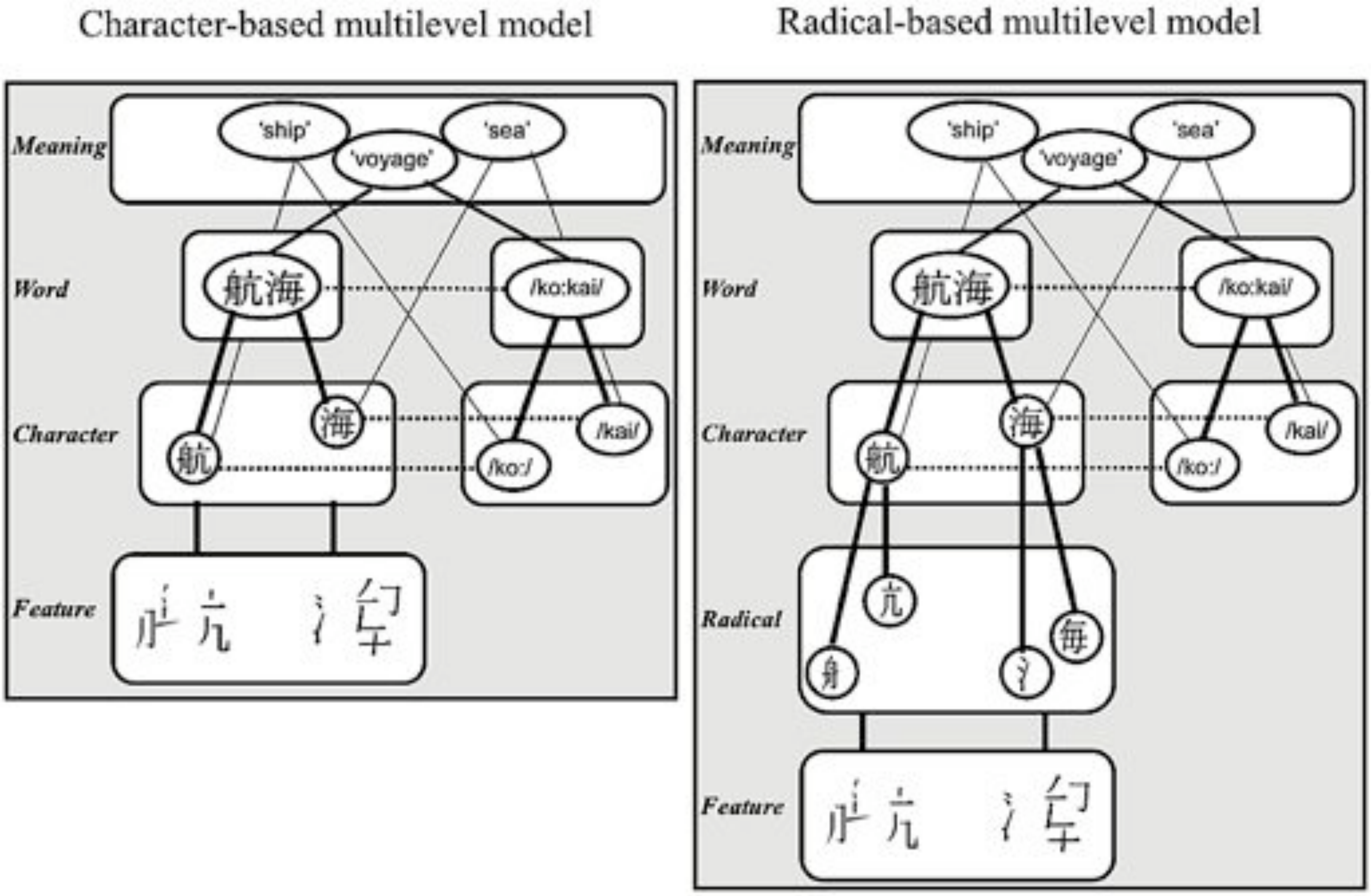
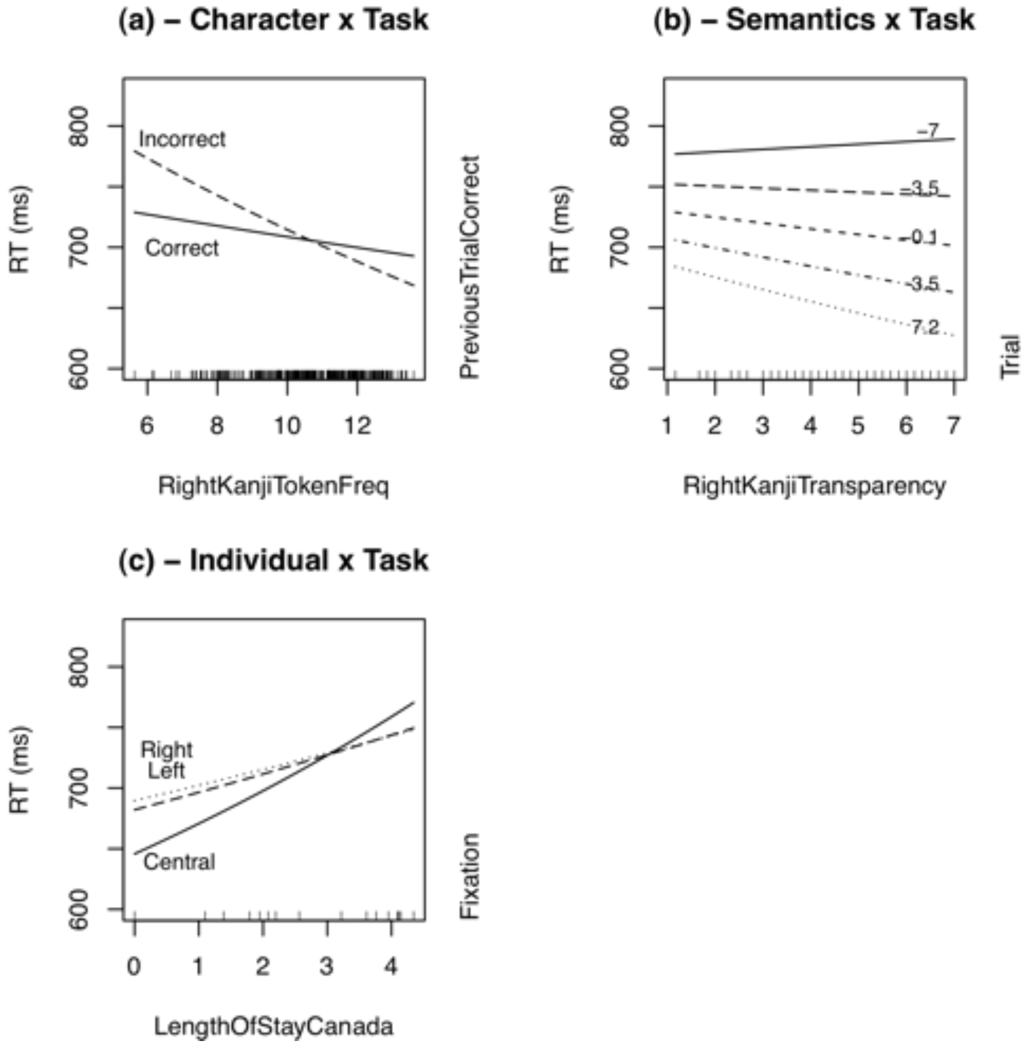

Character-based multilevel model
Radical-based multilevel model
Meaning
'ship'
'voyage'
'sea'
Word
航海
/ko:kai/
Character
航
海
/ko:/
/kai/
Radical
亢
舟
氵
毎
Feature

Figure 2

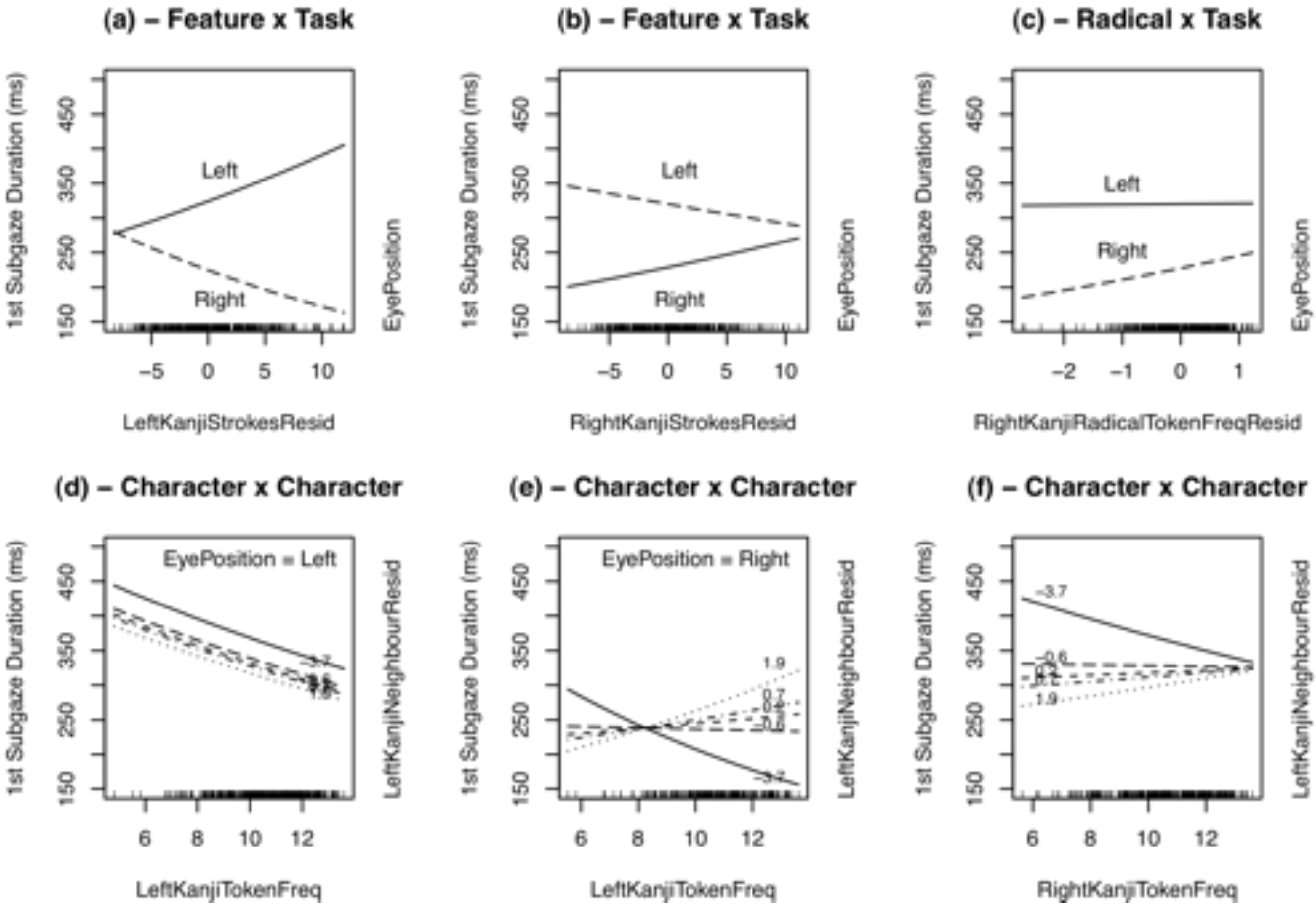


(a) – Character x Task

(b) – Semantics x Task

(c) – Individual x Task

Figure 3


(a) – Feature x Task

(b) – Feature x Task

(c) – Radical x Task

(d) – Character x Character

(e) – Character x Character

(f) – Character x Character

Figure 4

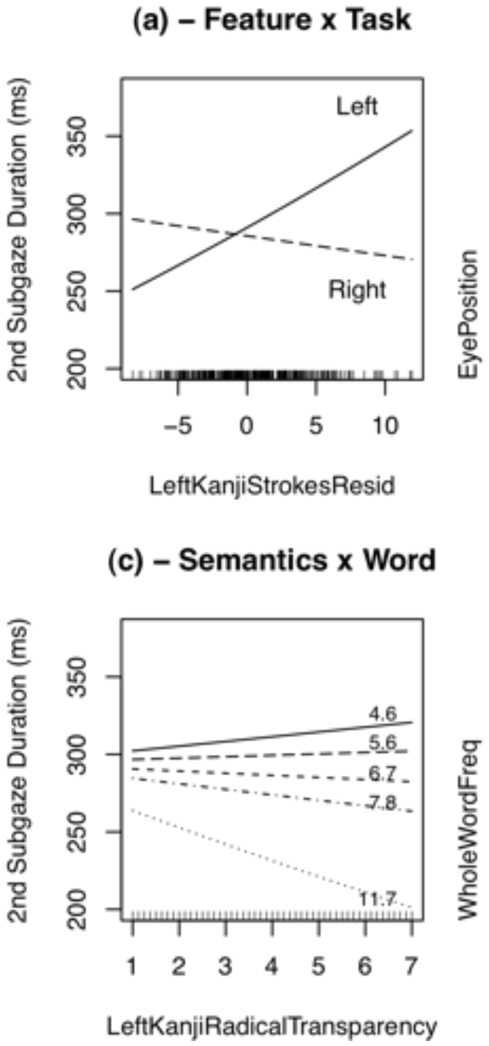
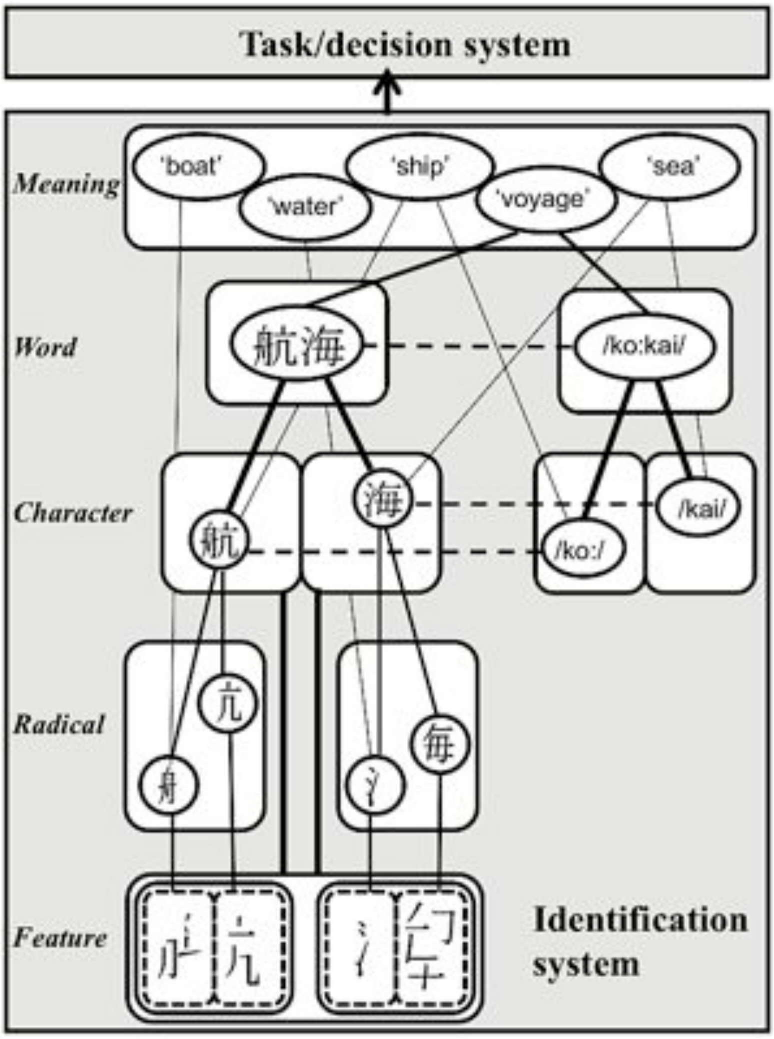

(a) – Feature x Task
2nd Subgaze Duration (ms)
200
250
300
350
Left
Right
EyePosition
–5
0
5
10
LeftKanjiStrokesResid
(b) – Feature x Task
2nd Subgaze Duration (ms)
200
250
300
350
Left
Right
EyePosition
–5
0
5
10
RightKanjiStrokesResid
(c) – Semantics x Word
2nd Subgaze Duration (ms)
200
250
300
350
4.6
5.6
6.7
7.8
11.7
WholeWordFreq
1
2
3
4
5
6
7
LeftKanjiRadicalTransparency

Figure 5


Task/decision system
Meaning
'boat'
'water'
'ship'
'voyage'
'sea'
Word
航海
/ko:kai/
Character
航
海
/ko:/
/kai/
Radical
舟
亢
氵
毎
Feature
Identification system

Word	Mean	SD
発表	657.86	185.85
全国	634.58	211.29
海外	790.75	327.37
被告	693.45	165.82
各国	674.68	155
連続	655.65	167.32
特別	662.42	272.94
番組	887.09	464.44
攻撃	637.03	169.29
営業	665.79	148.95
業務	670.97	130.97
購入	641.68	151.64
法律	794.26	363.34
空港	737.53	238.8
運用	796.63	285.49
所得	762.97	287.32
達成	661.82	105.2
歓迎	636.59	189.08
撤退	847.78	329.39
決算	718.5	142.71
財源	839.28	311.66
材料	626.2	105.36
出発	573.41	85.18
低迷	784.46	234.57
献金	999.26	557.7
交通	635.21	194.39
逆転	687.83	200.28
加入	623.22	154.17
魅力	602.48	99.33
食品	588.26	99.85
復活	637.5	160.76
介入	823.18	262.7
定着	676.93	217.82
入札	722.78	264.66
職業	614.62	110.23
人民	709.52	215.51
選出	773.4	260.61
借金	586.54	126.22
権力	677.19	164.56
増税	899.7	577.98
変動	695.69	197.08
名簿	667.68	116.23
運賃	700.75	213.74
武装	828.83	291.35
顧客	859.51	324.94
書類	646.57	110.83
文字	579.37	127.1
絵画	680.95	274.59
人類	577.88	81.15
診断	702.29	279.99
北部	745.96	196.3
予約	626.19	207.5
実務	736.61	410.57
釈放	826.71	298.96

在住	925.19	292.5
毎月	658.89	208.04
近所	611.7	158.61
修理	630.19	118.48
農地	753.9	177.17
矛盾	676.97	162.42
議題	810.82	214.34
当日	636.5	223.69
主任	671.11	194.27
拍手	613.78	144.07
増大	690.39	192.6
大陸	624.86	94.56
地図	592.92	176.1
広場	593.52	129
理論	809.98	374.9
本店	774.39	273.5
脱税	1101.14	519.03
急便	912.69	482.34
作者	649.98	118.04
漁船	874.69	357.45
再発	634.85	158.4
庶民	685.35	119.85
兵力	782.84	345.95
保全	958.68	372.78
通達	790.71	302.57
採算	879.12	347.59
残留	834.42	373.85
接続	658.32	152.45
面接	676.4	253.29
殺到	776.74	274.92
哲学	707.01	152.23
夕方	637.21	272.53
例年	776.72	364
数量	645.26	118.48
上陸	591.33	136.26
脱出	635.54	152.11
戦前	844.41	302.96
流入	703.52	255.67
棄却	889.91	395.59
移住	695.18	191.27
特許	880.2	381.63
除去	749.95	168.12
人形	566.49	91.93
輸血	923.2	556.43
親族	695.28	153.54
落選	795.78	272.22
目前	802.56	476.84
在宅	850.95	460.52
弾圧	737.09	198.26
文芸	700.21	197.12
我慢	669.36	185.66
老後	817.11	254.54
失望	592.98	112.16
満塁	919.72	343.13
概念	699.28	173.89

圧勝	831.55	458.58
出方	994.75	427.47
増収	918.64	360.18
反撃	635.48	168.96
捕鯨	883.34	250.66
風土	806.06	282.27
両手	594.9	143.3
東側	989.67	212.55
推測	786.52	300.53
毎週	681.38	247.25
祖父	666.77	166.99
薬物	729.04	232.76
客席	643.91	165.17
日数	834.85	501.84
学歴	579.47	105.6
病状	758.27	254.54
永住	1004.61	402.51
血圧	607.31	113.13
隣国	932.13	555.28
尊敬	740.24	237.29
直結	887.93	261.93
抑圧	950.35	412.54
備蓄	1001.82	300.69
経歴	675.14	143.9
脱却	893.95	365.31
月曜	726.55	325.73
脱皮	710.61	123.67
外務	781.99	277.06
規約	753.64	307.8
漁獲	985	325.32
偏見	756.14	295.14
発端	959.01	522.03
軍備	799.71	333.74
離陸	1172.31	730.43
文民	688.8	261.44
店内	733.74	187.84
論戦	1006.39	295.02
筋肉	714.09	362.53
決裂	752.75	247.71
圧倒	642.36	145.43
山中	725.46	242.85
責務	872.54	454.06
人格	616.1	114.34
入団	752.08	233.74
足場	728.55	251.83
無断	702.04	198.87
役職	728.58	206.89
在学	877.02	288.26
疑念	856.52	338.84
肥料	766.24	198.58
接点	699.11	173.79
出願	750.41	211.75
花火	619.54	169.2
稲作	780.44	269.17
半額	586.89	103.6

冷却	870.22	357.54
手腕	873.83	373.91
勤労	770.85	256.98
弱点	669.76	218.28
発明	593.5	131.09
下町	896.84	410.21
温存	813.56	201.51
牧師	678.7	130.24
贈与	872.75	273.92
適当	642.81	232.5
内科	702.61	213.85
用具	748.47	187.26
大雨	628.85	178.75
増発	1179.45	650.68
連発	612.65	179.96
定評	766.15	194.66
物品	899.15	519.87
留意	1018.35	558.23
体温	608.17	109.19
防護	1017.77	333.66
受託	823.66	289.27
雑貨	880.81	315.81
電流	704.28	147.67
書面	842.61	277.27
裏金	768.37	259.45
名所	784.36	295.43
破損	813.26	237.64
護衛	932.01	466.06
連中	686.51	134.79
左側	744.45	302.29
激突	693.33	243.82
花束	607.13	105.71
射撃	699.41	165.72
食物	659.66	251.74
発案	789.6	198.45
最悪	675.86	213.81
欠如	827.42	177.8
複雑	648.86	123.22
先日	630.35	150.73
伝票	676.97	132.17
必着	765.66	296.3
屈辱	852.32	271.35
時折	795.35	172.4
事柄	863.59	453.24
追突	735.91	303.1
巡査	714.62	91.65
隔離	1113.61	526.6
睡眠	615.87	107.59
発熱	720.2	222.32
本腰	744.92	229.6
難病	803.06	277.34
西暦	1054.41	471.91
先着	630.28	149.73
適切	790.68	491.24
外壁	883.16	405.19

腰痛	813.06	339.22
文楽	921.4	315.54
夏場	791.16	409.74
後手	833.58	235.77
北方	758.62	242.38
没収	873.51	619.85
総勢	940.27	478.37
下宿	639.02	92.64
重力	657.31	140.66
雨量	997.66	504.38
自決	886.03	357.27
緑地	961.88	433.21
不便	804.13	320.26
片方	757.65	235.75
奪還	1059.92	454.66
翌朝	689.92	170.92
割安	796.38	328.52
婚約	788.51	326.28
吟味	871.89	271.81
難関	786.02	269.75
忍耐	709.83	214.42
国務	756.25	189.4
大雪	724.4	216.05
標本	776.73	311.64
混在	872.01	562.23
失明	821.45	330.35
水着	590.5	119.26
遭遇	940.65	411.93
順序	729.44	288.04
失格	601.18	117.57
英字	900.54	420.76
総督	843.17	197.58
能率	752.12	193.14
合作	893.92	483.37
放流	819.1	357.05
世襲	855.43	297.83
失墜	794.92	273.8
実弟	1089.16	390.34
序列	728.89	199.53
来賓	942.11	287.46
粉末	734.65	246.13
送迎	805.62	283.52
始発	744.29	128.26
暗示	680.81	151.17
紅茶	678.84	158.07
尾根	1025.33	292.24
下山	811.08	322.84
装着	789.42	215.38
気圧	646.01	136.95
風穴	973.03	253.1
各論	882.73	374.42
新米	790	261.74
図柄	912.81	331.56
献立	810	279.18
壁面	873.47	449.16

内陸	691.59	221.67
中級	694.44	159.42
返納	949.26	300.84
露出	826.41	325.45
蔵書	1034.77	531.33
浴室	727.94	225.97
古来	750.97	139.57
土産	797.31	324.66
号令	773.38	206.77
出撃	742.84	303.96
増刷	1095.62	639.66
切除	757.93	254.88
独断	728.91	213.55
有望	845.72	333.31
半値	845.53	250.22
弾丸	818.45	491.03
自筆	783.99	250.05
下地	958.09	418.73
屋敷	941.58	344.36
喫茶	726.53	218.03
点差	1208.96	461.85
強火	884.92	318.25
乗馬	670.91	130.29
口先	780.57	279.93
天文	914.51	538.8
横顔	752.33	236.18
各駅	754.89	199.31
外野	1066.28	704.41
嫌悪	805.33	265.16
点滅	845.39	378.49
出前	639.18	192.08
役柄	665.51	168.14
百姓	1013.26	546.27
活性	865.69	362.41
許諾	1108.96	519.82
力作	755.73	145.76
代役	700.75	193.84
熟知	865.26	480.86
来世	835.83	199.78
煮汁	949.67	360.34
分量	653.26	126.41
不発	849.79	529.51
断水	743.07	247.21
中火	856.44	268.2
油圧	1147.05	653.12
急激	741.12	276.24
束縛	782.2	218.09
祝辞	1143.62	718.32
年輪	945.92	274.11
下水	798.99	404.24
液状	964.17	265.88
街路	1022.4	501.12
突進	815.02	322.01
酒場	805.18	288.51
筆記	819.69	314.56

戦乱	833.18	314.46
上達	709.96	238.79
出塁	1087.38	546.1
挙式	810.17	242.56
悪意	777.86	263.01
逆襲	783.68	283.79
格納	998.48	429.24
半月	729.88	216.53
常習	855.08	338.95
蛇口	842.03	197.66
編者	913.55	316.23
頭髪	801.51	244.71
激怒	698.92	214.92
初任	961.11	380.49
爆音	751.37	226.02
水際	794.88	295.85
従属	1017.62	458.81
北国	664.8	195.01
寸断	815.18	273.56
中途	787.66	265.65
胸中	793.09	191.22
月面	896.94	517.62
田園	830.58	206.23
不運	692.62	168.14
良質	717.78	257.41
風圧	879.53	227.78
発育	746.39	251.71
翌月	747.81	289.72
炊事	714.81	179.61
実数	756.38	187.04
来場	1068.16	463.89
麻布	1146.83	363.73
印税	737.28	188.38
和室	655.33	152.38
暗雲	859.72	506.22
伝来	744.05	251.92
勉学	885.85	472.65
門下	1111.74	660.43
小指	777.2	347.08
低空	972.87	355.68
口数	964	467.01
木馬	747.77	300.62
本領	780.43	237.25
仲人	796.38	221.85
静寂	924.68	417.71
即興	939.68	389.03
野望	800.31	358.11
一息	677.01	134.3
集客	883.82	403.47
王族	824.14	259.29
絵筆	863.57	392.7
王女	771.88	367.25
木箱	778.82	203.54
目頭	823.39	341.8
直腸	1122.62	366.64

純金	802.92	330.45
安泰	826.23	225.06
熱水	863.63	305.32
余白	716.08	168.82
激務	950.25	443.67
電撃	830.77	320.72
花園	725.92	336.9
船旅	730.79	265.34
噴水	746.46	287.2
子役	670.11	159.81
山腹	802.34	326.98
耐熱	863.4	390.25
急病	809.38	280.58
学識	770.86	290.75
号外	885.57	358.61
利得	742.26	276.35
赤道	964.35	484.47
失態	825.09	430.22
黒幕	741.44	244.6
極刑	810.29	268.55
値札	655.01	110.18
返金	673.71	143.75
自炊	785.26	455.52
満面	973.95	339.68
肉食	721.91	156.11
眼前	1008.08	578.96
緑茶	793.58	363.55
短冊	972.74	407.06
面相	1257.68	562.35
吸入	866.93	303.08
数式	648.74	211.31
猟銃	1222.72	615.98
王妃	774.64	224.48
冬物	771.47	202.05
芸風	889.33	521.16
悪徳	883.01	289.44
隊列	840.86	283.65
分立	878.13	529.61
名著	884.25	311.79
裏表	845.66	198.36
片腕	874.8	297.63
納品	734.43	322.48
肌着	804.51	309.17
畑作	983.6	404.35
男役	730.13	162.11
別格	757.35	217.02
学外	812.98	314.13
種別	846.14	286.7
度量	1015.8	551.36
大船	794.44	217.56
城跡	982.63	418.74
祝祭	856.42	278.89
地道	702.96	189.21
自腹	697.69	220.13
直筆	739.67	216.5

木彫	868.41	226.94
養豚	1253.89	327.5
長旅	839.94	502.52
話術	801.8	193.48
分派	880.63	425.3
船便	845.54	398.89
熱風	867.75	269.61
医務	722.43	155.96
倹約	891.88	381.33
守衛	839.55	378.57
応接	908.39	435.26
薄型	898.57	456.74
日給	870.6	292.7
突発	822	409.27
突撃	669.77	174.34
軟式	806.08	134.43
訳語	811.15	236.08
書画	1087.05	500.55
安静	754.04	271.59
早晩	886.96	437.83
出陣	705.12	144.48
統率	922.84	451.01
不意	886.97	309.64
劇作	990.69	518.32
素足	774.77	286.12
離任	908.97	325.13
時雨	1177.1	536.43
速達	783.87	299.17
遠出	814.51	361.69
最愛	850.39	281.28
歴然	843.4	303.93
銀貨	898.8	245.76
目次	866.57	518.51
道中	814.82	275.55
画材	793.11	180.53
私欲	817.13	194.27
漫談	981.11	368.19
邪道	788.28	272.91
汚物	710.18	152.51
周遊	879.66	357.24
内海	884.77	358.75
腹筋	857.43	431.59
満室	669.98	169.78
絶壁	1068.73	437.67
策略	763.9	206.81
岩山	803.48	219.44
内勤	813.73	351.4
壁紙	745.49	180.06
脱輪	1079.02	478.09
夜半	902.25	403.46
執事	839.3	534.17
語尾	726.86	250.63
窓辺	892.5	460.31
雑穀	920.99	225.82
古傷	812.65	164.62

彼方	857.12	285
学割	686.58	151.14
珍味	816.21	290.84
沈着	855.64	362.73
悪事	693.92	182.71
財力	773.99	231.94
白雪	795.9	359.89
残像	838.29	286.21
花弁	911.14	305.92
手玉	758.03	372.8
迷宮	852.8	537.06
分冊	912.54	411.96
血筋	728.75	234.78
悲恋	933.92	177.15
冷酷	951.66	516.69
横幅	1012.48	482.55
厚板	1269.61	776.79
片親	828.67	250.02
満潮	868.96	243.65
板前	860.37	309.4
明朗	1109.35	498
貧農	1130.15	562.41
露骨	772.48	160
音信	776.21	213.3
仏画	989.82	330.07
入店	790.84	233.78
非番	927.73	339.36
余興	948.98	550.2
白地	741.17	253.81
火柱	1114.09	664.2
変人	617.1	104
巣穴	912.35	359.15
女心	837.42	182.77
民選	995.19	280.65
絶妙	843.56	360
仏前	783.08	186.72
落馬	732.9	180.58
届出	927.76	352.9
博愛	870.35	459.93
道順	985.12	440.69
魅惑	807.7	287.06
水難	935.1	514.46
福袋	769.38	271.55
病魔	915.87	231.27
汗水	962.79	576.36
起案	875.27	253.52
拝借	870.08	228.67
求愛	804.28	196.23
片時	919.29	244.14
熟睡	815.02	238.12
術中	746.94	265.13
安眠	619.84	92.02
手塩	888.82	409.06
珠玉	1076.91	550.93
茶畑	789.99	223.17

幼年	1035.48	519.92
欄外	782.02	164.09
愛妻	904.76	358.5
美食	886.11	309.94
縮尺	1021.7	369.48
試着	740.73	260.87