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The role of interword spacing in reading Japanese: An eye movement study ☆

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Abstract

The present study investigated the role of interword spacing in a naturally unspaced language, Japanese. Eye movements were registered of native Japanese readers reading pure Hiragana (syllabic) and mixed Kanji–Hiragana (ideographic and syllabic) text in spaced and unspaced conditions. Interword spacing facilitated both word identification and eye guidance when reading syllabic script, but not when the script contained ideographic characters. We conclude that in reading Hiragana interword spacing serves as an effective segmentation cue. In contrast, spacing information in mixed Kanji–Hiragana text is redundant, since the visually salient Kanji characters serve as effective segmentation cues by themselves.

Keywords: Reading; Space; Fixation; Saccade; Japanese

1. Introduction

Interword spacing is a salient visual cue to indicate boundaries between words in text. Thus, it is suggested that interword spaces are highly important when reading Roman script (e.g., Rayner, 1993; Rayner & Morris, 1992). In the present study, we investigated the reading of a naturally unspaced language—Japanese—that does not use interword spacing in its ordinary script. However, Japanese readers are to some extent used to interword spacing, as children are initially taught to read spaced Hiragana (syllabic script). Thus, Japanese provides a good opportunity to investigate the role of spacing as a segmentation cue in reading.

Studies of Roman script have shown that removing spaces or filling spaces with extraneous letters slows down reading by 30–50% (e.g., Malt & Seamon, 1978; Morris, Rayner, & Pollatsek, 1990; Pollatsek & Rayner, 1982; Rayner, Fischer, & Pollatsek, 1998; Spragins, Lefton, & Fisher, 1976). Rayner et al. (1998) put forward three alternative hypotheses about the role of spacing in reading: it facilitates (1) word identification, (2) eye movement guidance, or (3) both.

Rayner et al. (1998) manipulated both word frequency and spacing and found a main effect in gaze duration for both factors (high-frequency words and words in the spaced conditions were fixated for shorter time than low-frequency words and words in the unspaced conditions) as well as an interaction between word frequency and interword spacing. The interaction reflected the finding that the removal of spaces lengthened gaze duration to a greater extent for low than for high frequency words. This led the authors to argue—following the additive factors logic of Sternberg (1969)—that spacing interferes with the pro-

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cess of word identification. In other words, if word identification would not have been affected by spacing, the word frequency effect should have been equal in size for both the spaced and the unspaced text.

Rayner et al. (1998) also found that interword spacing contributes to eye movement guidance. When spaces were available, the initial fixation location, referred to as the *preferred viewing location* (PVL, Rayner, 1979), was close to the word center, whereas in the unspaced text PVL shifted to the word beginning. Even though the removal of spaces had a significant influence on the PVL, it is noteworthy that a word-based pattern was preserved also for words not separated from each other by spaces. As the word center is the most optimal site for word processing (*optimal viewing position* = OVP; McConkie, Kerr, Reddix, & Zola, 1988; O'Regan, 1981; O'Regan & Jacobs, 1992; O'Regan, Lévy-Schoen, & Pynte, 1984), removing spaces results in a less optimal landing position leading to a longer gaze duration and more refixations on a word (Rayner et al., 1998).

The widely held view about the facilitative nature of spaces in reading Roman script was questioned by Epelboim, Booth, and Steinman (1994; 1996), who reported that the effect of removing spaces was modest and that it was mostly reflected in slightly lengthened mean fixation durations indicating difficulty in word recognition (see also Epelboim, Booth, Ashkenazy, Taleghani, & Steinman, 1997) rather than in saccade programming (they did not detect changes in PVL). These findings were criticized by Rayner and Pollatsek (1996), who noted that most of the participants in these studies showed the normal 30–50% decrement when interword spaces were removed. They also suggest that the reason for the more moderate effects observed by Epelboim and colleagues compared to other studies may be due to their experimental texts being very easy and some of the participants being well-trained in reading unspaced text. Hence, we may conclude that spacing information is found to facilitate reading of Roman script by effectively guiding the eyes toward the optimal viewing location and by speeding up the process of word identification, in line with the third hypothesis put forth by Rayner et al. (1998).[1]

Most spacing studies conducted in Roman script suffer from the fact that readers are unaccustomed to reading unspaced text. Thus, the disruption effects in reading due to the removal of spaces may at least in part be ascribed to a non-familiar text format. However, this argument does not apply to the study of Kohsom and Gobet (1997) conducted in Thai, which has its own alphabet. Although words are considered to be the basic units of the language, in Thai no spaces are added between words. Interestingly, Kohsom and Gobet found that interword spacing increased the reading speed somewhat, although the increment remained statistically marginal. This increase came as a surprise to the Thai readers, because they felt that reading spaced Thai was harder than reading unspaced Thai.

The role of spacing has also been investigated in Chinese, a non-alphabetic language that does not use spaces between words (what is considered a word is not as clear-cut as in Western languages). Liu, Yeh, Wang, and Chang (1974) found that adding spaces did not increase reading speed. Furthermore, Yang and McConkie (1999) failed to establish the PVL phenomenon for Chinese: eye fixations were positioned quite evenly throughout the text, and no word-based pattern was observed for the initial fixation location. Thus, as spacing appears to be of little use, Tsai and McConkie (2003) propose that eye guidance in reading Chinese is based on some other property of the text than words. However, Rayner, Li, and Pollatsek (2007) recently simulated the eye movements of Chinese readers in the context of the E-Z Reader model (which is word-based), and the model provided a good account of the data.

1.1. The Japanese language

The Japanese language provides a multifaceted opportunity to investigate the role of interword spacing and other visual cues in reading. The Japanese writing system evolved from Chinese ideographs, *Kanjis*, introduced to Japan in the 5th century (Kuratani, Kobayashi, & Yoshida, 1990). Kanji characters, which usually have more than one pronunciation, are morphemes representing independent meaning units. However, Japanese, being an agglutinative language as it uses a variety of inflectional and postpositional endings, could not be represented sufficiently by Kanjis. Therefore, a unique Japanese syllabary, *Kana*, was created that consists of two sets of 46 syllable-based characters, *Hiragana* and *Katakana*. Hiragana is used to mark grammatical structures like conjugations and function words, and Katakana mostly to write foreign names and loan words. A typical Japanese text is a mixture of these three character types and is comprised of 30% Kanji characters (Matsuda, 1998).

The Hiragana syllabary may also be used to represent Kanji characters. Consequently, every Kanji can be written in Hiragana, and this is indeed done in teaching written Japanese to foreigners and children. Moreover, for teaching purposes spaces are added to the Hiragana text, which means that (1) the basic reading skill is acquired via reading pure Hiragana script, and (2) Japanese readers are not totally unaccustomed to reading spaced text (although the standard script is unspaced). Thus, Japanese offers an interesting "test bed" to study the role of interword spacing both in reading syllabic and idiographic script.

Japanese is a word-based language although segmenting a text into words is not as clear-cut as in languages using spacing as a rule. Spacing can be done at least in two ways. One is by adding spaces not only between words but also between their grammatical modifiers and postpositions.

[1] Note, however, that when spaces are inserted between unspaced compound words, the extraction of compound meaning is hampered (Inhoff, Radach, & Heller, 2000; Juhasz, Inhoff, & Rayner, 2005).

This method resembles, for example, written English, and it is used when a text is romanized, usually in the context of teaching Japanese for foreigners. The other option is to consider the modifiers and postpositions as a part of the modified word.[2] This latter method is often seen in children's books written mostly in Hiragana.

The Japanese language has been subject to some eye movement experiments The perceptual span in reading Japanese Kanji–Hiragana mixed text is demonstrated to be around 5–6 characters (3–4 characters to the right of fixation; Osaka, 1993; Osaka & Oda, 1991). Osaka (1989), Osaka (1992) compared the reading of pure Hiragana text to that of mixed Kanji–Hiragana text (both unspaced). He found that reading pure Hiragana text was slower than reading Kanji–Hiragana mixed text. This was reflected in longer eye fixations and shorter saccades. In the Osaka (1992) study the mean fixation duration in the pure Hiragana text was 208 ms, while for an equivalent Kanji–Hiragana mixed text it was 190 ms. Even though mixed Kanji–Hiragana text is more compressed than pure Hiragana, average saccade length was two characters longer in Kanji–Hiragana than in pure Hiragana (the means were 7.2 and 5.2 characters for Kanji–Hiragana and pure Hiragana, respectively). He also found that the perceptual span in reading Hiragana is smaller (five characters) than in reading Kanji–Hiragana mixed text (seven characters). On the basis of these data, Osaka concluded that Kanji characters facilitate the processing of written Japanese.

Kajii, Nazir, and Osaka (2001) observed similarities between reading naturally unspaced Japanese and unspaced English. In both scripts, PVL is in the beginning of the word (see Rayner et al., 1998, for unspaced English). Interestingly, Kajii et al. also discovered that, similarly to English, the probability of refixating a word was highest when the initial fixation landed on the first character in a word.

Kajii et al. (2001) also tested the proposal made by Kambe (1986) that character shifts (i.e., between Kanji and Hiragana) are efficient visuo-lexical cues for word boundaries, and consequently, facilitate word identification. Kajii et al. demonstrated that Kanji characters receive, on average, more fixations than Hiragana and Katakana characters, which suggests that the visually salient Kanjis are eye-catching. Moreover, the character composition in a word influenced the PVL pattern: only when a Kanji character was at the beginning of a word, a PVL was found (i.e., readers preferred to fixate first on the Kanji character appearing as the initial character of the word). For pure Hiragana words the initial fixation did not differ between different character positions. Thus, the character composition in a word was concluded to be the main component in eye movement guidance, the more complex Kanji characters being the focus of eye fixations and visual attention.

[2] Matsuda (2001) uses the term "inter-clause spacing" to refer to this second method of spacing, which is here referred to as interword spacing.

1.2. The present study

In the present study, we examined the effects of interword spacing in two kinds of Japanese texts: *pure Hiragana* and *mixed Kanji–Hiragana*. This resulted in four experimental conditions: *unspaced Hiragana* (HUSP), *spaced Hiragana* (HSP), *unspaced Kanji–Hiragana* (KUSP), and *spaced Kanji–Hiragana* (KSP). As noted above, adding spaces between words violates the standard writing convention, particularly for the mixed Kanji–Hiragana text. Thus, possible facilitatory effects of spacing cannot be ascribed to readers being more familiar with the spaced text format.

As Hiragana bears similarity to alphabetic script, we expected spacing to facilitate reading of Hiragana. The facilitation was assumed to show up both as faster word identification, which would be seen particularly in word-level fixation time measures, and as more optimal saccadic programming reflected in saccade length and initial landing position in a word. On the other hand, we expected spacing to be less effective in reading mixed Kanji–Hiragana text. This prediction is based on earlier studies showing that salient Kanji characters are effective visual cues in guiding the eyes through a text. Hence, spaces may not be of additional help. Another possibility is that combining two visually salient word segmentation cues, Kanjis and spaces, may lead to processing benefits, both by facilitating word identification and by guiding the eyes optimally. Also, inserting spaces at word boundaries could make word-initial Kanjis visually more salient, thus attracting the eyes toward them more often than in the unspaced condition. Yet another alternative is that adding spaces may enhance parafoveal processing of word-initial Kanjis and thus enable the following fixation to land further in the word.

It should be noted that our study is not the first eye movement study that investigated the role of spacing in Japanese. A similar study was conducted by Matsuda (2001) who also examined native Japanese readers reading spaced and unspaced Hiragana and mixed Kanji–Hiragana text. However, this study was somewhat exploratory in nature. First, the experiment, published in Japanese, included only four participants. Second, the relative sequence of the different conditions was not counterbalanced across participants; for all participants the spaced condition was preceded by the unspaced condition for either the Hiragana or the Kanji–Hiragana texts, or both. Hence, a more comprehensive and better controlled study on this issue is called for.

2. Method

2.1. Participants

Sixteen students or personnel from the Chukyo University (Nagoya, Japan) participated in the study. Their age ranged from 18 to 35 years. They were all native Japanese speakers with normal or corrected-to-normal vision. The inclusion criterion was that the participant had comprehended the main points of the texts.

2.2. Apparatus

Eye movements were recorded with EyeLink I (SR Research, Canada). The sampling rate of the system is 250 Hz (i.e., a temporal resolution of 4 ms). In order to minimize head movements during reading, a chinrest was used; the participants were also asked not to move during reading. There is also a head movement compensation system built in the eye-tracker. Only the movements of the right eye were recorded except for one participant whose left eye (apparently the dominant one) was used.

2.3. Materials

Four text passages were selected for the experiment. The passages were excerpts from daily columns in Internet newspapers with a length of around 60 words. Six students, who did not participate in the experiment, rated the difficulty level of the texts. The average difficulty varied between 4.2 and 5.2 with an average of 4.8 in a scale from 1 (difficult) to 7 (easy). Four versions of each text were prepared: (1) pure Hiragana without spacing (HUSP), (2) pure Hiragana with spacing (HSP), (3) mixed Kanji–Hiragana without spacing (KUSP), and (4) mixed Kanji–Hiragana with spacing (KSP). In Table 1, an example sentence from one of the texts is shown in all four text types.

The pure Hiragana texts comprised on average 265 characters, while the mixed texts contained on average 199 characters, of which an average of 86 were Kanji characters. The mean number of words in a text was 61.5, and the number of lines was 11 or 12. The whole text was presented on a single screen. The number of words on a line was kept constant across the text types, which naturally resulted in longer lines in the pure Hiragana texts than in the mixed texts. For the spaced texts, spaces were inserted between words so that the grammatical modifiers and postpositions at the end of words were not separated by spaces. In the mixed Kanji–Hiragana text, on average, 19% of words did not contain any Kanji, 30% contained one, 44% two, and 7% three Kanjis (only one word in one text contained four Kanjis). When the word contained Kanji characters, they were commonly found in the word beginning. Only few words started with a Hiragana character (prefix) followed by one or more Kanji characters, or had a pattern of a Kanji followed by a Hiragana character and then continuing with a Kanji again. It should be noted that the pure Hiragana words in the mixed Kanji–Hiragana texts were also included in the data analyses. Moreover, we also conducted separate analyses for pure Hiragana words in the mixed texts.

In addition to the four experimental texts, four practice texts were selected. These texts were about the same length as the experimental texts and were used in order to familiarize the participant with the subsequent condition. Thus, each participant read in total eight passages: one practice text and one experimental text from each condition. Each experimental text was preceded by a practice text. The four texts were counterbalanced between participants across the four conditions. The order of the four experimental conditions was also counterbalanced, which resulted in 16 different combinations.

The text passages were presented on the computer screen in white characters on a black background. MS Mincho font was used; in that font, each character occupies a space of equal size. The font size was 21. With a viewing distance of 63 cm, one character extended approximately 1 degree of visual angle. The spaces between words occupied one character space, and the line spacing was 1.5. The screen size was 38.4 cm × 29.1 cm.

2.4. Procedure

Each participant was instructed to read the texts silently for comprehension in normal reading speed. Before the experiment, the participant was familiarized with the apparatus, and the eye-tracker was calibrated. The calibration was repeated between the texts. After the calibration, the instructions were repeated on the computer screen. Reading was self-paced; after reading the text, the participant pressed a button to terminate the data collection. Each experimental text was followed by a comprehension question; the participant was asked to explain orally the main idea of the text.

2.5. Data analyses and design

Both text-level and word-level measures were computed from the eye movement data. In the text-level analyses, we used the following *global eye movement measures*: reading rate, percentage of regressions, average fixation duration, and average forward saccade length. For the *word-level analyses,* we computed first fixation duration, gaze duration, total fixation time, and total number of fixations per word. In addition, we also conducted *PVL analyses*, which yielded word-specific measures for the *OVP analyses.* The experimental design was 2 (Text Type) × 2 (Spacing); in the PVL and OVP analyses, we employed a 2 (Text Type) × 2 (Spacing) × 3 (Word Zone) design. A series of repeated measures analyses of variance (ANOVAs) were computed on the aforementioned eye movement parameters.

3. Results

3.1. Text-level analyses

The means and standard deviations of reading rate, percentage of regressions, average fixation duration, and average forward saccade length are listed in Table 2.

Table 1
An example sentence as it appeared in the four experimental conditions

Text type	Spaced	Unspaced
Hiragana	なりた　くうこうの　けいえいは げんじょうでは　おせじにも　ゆう りょうとは　いえない。	なりたくうこうのけいえいはげ んじょうではおせじにもゆうり ょうとはいえない。
Kanji- Hiragana	成田　空港の　経営は　現状では お世辞にも　優良とは　いえない。	成田空港の経営は現状ではお世 辞にも優良とはいえない。
English	The management of Narita airport can by no means said to be excellent	

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Table 2
Means (standard deviations) of the text-level eye movement measures, as a function of text type (H, Hiragana; K, mixed Kanji–Hiragana) and spacing (USP, unspaced; SP, spaced)

	HSP	HUSP	KSP	KUSP
Reading rate (words/min)	88 (27)	78 (26)	108 (33)	120 (37)
Percentage of regressions	23.3 (7.9)	23.6 (5.8)	19.7 (8.1)	18.4 (8.8)
Average fixation duration (ms)	240 (28)	250 (27)	247 (28)	257 (38)
Average forward saccade length (characters)	4.0 (1.0)	3.1 (0.8)	3.7 (0.9)	3.2 (0.8)

The overall reading rate (words per minute) indicates that Hiragana texts (83 wpm) were read less efficiently than mixed Kanji–Hiragana texts (114 wpm), indexed by a significant main effect of text type, $F(1,15) = 59.58$, $p < .001$. There was no main effect of spacing, but the interaction between text type and spacing proved significant, $F(1,15) = 4.46$, $p = .05$. The separate pairwise t tests between the spacing conditions did not reach significance for either text type: The reading rate in the HUSP text tended to be slower than that in the HSP text, $t(15) = 1.76$, $p = .10$. For the mixed Kanji–Hiragana text, there was an opposite tendency (spaced text was read slower than unspaced text), $t(15) = 1.61$, $p = .12$.

It may be noted that the reported reading speed is considerably slower than what is observed for English. This notable difference is more apparent than real, as we did not include in our word counts the function words as separate words. When the reading rate was computed for the unspaced texts by treating the short function words as separate words, the reading rate was 200 words per minute for the mixed Kanji–Hiragana text and close to 150 words per minute for the pure Hiragana text. When measured in characters per minute (cpm), our reading rates (343–389 cpm) are greater than or comparable to those reported by Osaka (1993) for Kanji and Hiragana (about 200–400 cpm, depending on his experimental condition).

The percentage of regressions showed a main effect of text type, $F(1,15) = 18.78$, $p < .001$, but not of spacing. The Hiragana texts produced more regressions (23.4%) than the mixed Kanji–Hiragana texts (19.1%). The interaction between text type and spacing was non-significant.

The average fixation duration showed a slightly different pattern from that of reading rate and percentage of regressions. There was a main effect of spacing, $F(1,15) = 13.20$, $p < .01$, and a marginally significant main effect of text type, $F(1,15) = 3.65$, $p = .08$. Average fixation duration was shorter when reading spaced (243 ms) than unspaced (254 ms) text. It also tended to be shorter in reading Hiragana (245 ms) than mixed Kanji–Hiragana (252 ms).

The average forward saccade length was, naturally, longer in the spaced (3.9 characters) than in the unspaced (3.1 characters) text, as revealed by a main effect of spacing, $F(1,15) = 44.34$, $p < .001$. More interestingly, the interaction between text type and spacing also proved significant $F(1,15) = 11.52$, $p < .01$. Pairwise t tests revealed that the difference between the spaced and unspaced version was significant both for Hiragana, $t(15) = 8.74$, $p < .001$, and for mixed Kanji–Hiragana, $t(15) = 3.30$, $p < .01$. Additionally, the difference between KSP and HSP was also significant, $t(15) = 3.24$, $p < .01$; the spaced Hiragana text was read with longer forward saccades than the spaced Kanji–Hiragana text.

In sum, as regards the overall reading rate and percentage of regressions, the results indicate that the reading of normal Japanese script (i.e., including Kanji characters) does not benefit from spacing, but there was some indication in reading rate and forward saccade length that reading pure Hiragana is facilitated by spacing. The effect of spacing observed in average fixation duration for both texts may be interpreted to suggest that spacing helps in moving faster to a new text location. However, it should be noted that in the Kanji–Hiragana text shorter fixations for the spaced text did not translate into faster reading speed; in fact an opposite trend was observed (see also the word-level analyses below).

3.2. Word level analyses

The word-level eye movement parameters reflect different stages of word processing. First fixation duration and gaze duration index word processing when each word is encountered for the first time (i.e., prior to fixating away from it), while total fixation time and total number of fixations also include regressions back to the word. The skipping rate indicates the percentage of words that are read without directly fixating them. The means and standard deviations of the word-level parameters are presented in Table 3.

No significant effects were observed in *the first fixation duration*. In *gaze duration* (Fig. 1) and *total fixation time* the main effect of text type was significant, $F(1,15) = 24.26$, $p < .001$ and $F(1,15) = 66.90$, $p < .001$, and the main effect of spacing was marginally significant, $F(1,15) = 4.23$, $p = .06$ and $F(1,15) = 3.34$, $p = .09$, for gaze duration and total fixation time, respectively. Fixation times were longer for the Hiragana text (gaze 455 ms, total 624 ms) than for the mixed Kanji–Hiragana text (gaze 377 ms, total 445 ms). As there was also a hint of an inter-

Table 3
Means (standard deviations) of the word-level eye movement measures, as a function of text type (H, Hiragana; K, Kanji–Hiragana) and spacing (USP, unspaced; SP, spaced)

	HUSP	HSP	KUSP	KSP
First fixation duration (ms)	258 (27)	258 (43)	266 (33)	264 (32)
Gaze duration (ms)	480 (122)	430 (130)	384 (131)	370 (82)
Total fixation time (ms)	664 (178)	581 (186)	441 (168)	449 (133)
Total number of fixations/word	2.7 (0.6)	2.4 (0.6)	1.7 (0.4)	1.9 (0.4)
Skipping rate (%)	4.9 (6.2)	2.2 (3.0)	10.7 (10.5)	3.6 (6.1)

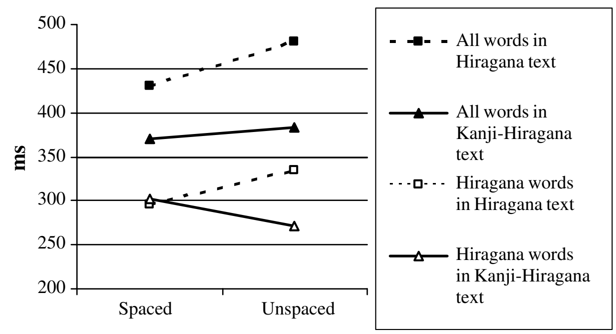

Fig. 1. Gaze duration as a function of text type and spacing, for the complete set of words and for a subset of Hiragana words appearing in the pure Hiragana and in the mixed Kanji–Hiragana text.

action in gaze duration, $F(1,15) = 2.53$, $p = .13$, and in total fixation time, $F(1,15) = 2.85$, $p = .11$, the spacing effect was further examined by pairwise t tests computed separately for the Hiragana and mixed Kanji–Hiragana text. The 50 ms benefit of spacing in gaze duration in the Hiragana text was significant, $t(15) = 2.35$, $p < .05$, but the 14 ms difference between spaced and unspaced text in mixed Kanji–Hiragana was not ($t < 1$). Similarly, the 83 ms benefit of spacing in total fixation time was significant in the Hiragana text, $t(15) = 2.37$, $p < .05$, whereas the 7 ms difference between spaced and unspaced text in Kanji–Hiragana was not ($t < 1$).

The total number of fixations per word showed similar effects as the fixation time measures. The main effect of text type, $F(1,15) = 88.21$, $p < .001$, reflects the fact that the Kanji–Hiragana text was read with fewer fixations per word (1.8) than the Hiragana text (2.5). Moreover, the Text Type × Spacing interaction proved now significant, $F(1,15) = 4.53$, $p < .05$,. Similarly to the fixation time measures, spacing yielded a facilitatory effect in Hiragana, that was close to significant, $t(15) = 1{,}77$, $p = .10$, but the difference between the spaced and unspaced text in Kanji–Hiragana was not significant ($t < 1$).

In order to find out whether the facilitatory spacing effect observed for the pure Hiragana text generalizes to the Hiragana words that appeared in the Kanji–Hiragana text, we analyzed the gaze duration for the 46 words of the Kanji–Hiragana text that were written in pure Hiragana (Fig. 1). For direct comparisons, the data for exactly the same words were analyzed in the pure Hiragana text. Interestingly, the Hiragana words in the Kanji–Hiragana text did not benefit from spacing. In fact, unspaced text yielded slightly shorter gaze durations for Hiragana words than spaced text, whereas in the unspaced Hiragana text Hiragana words were read with longer gaze durations than in the spaced text Hiragana text. This pattern was confirmed by a reliable interaction between text type and spacing, $F(1,15) = 4.96$, $p < .05$. In other words, the analysis showed that the smaller sample of Hiragana words of the pure Hiragana text elicited a similar pattern of gaze durations as the complete set (longer gaze durations in the unspaced than in the spaced condition), whereas in Kanji–Hiragana text the Hiragana words behaved similarly to Kanji–Hiragana words (i.e., words that contained both Kanji and Hiragana characters). Additionally, the same Hiragana words were read much faster when they appeared in the unspaced Kanji–Hiragana text than when they appeared in the unspaced Hiragana text, $t(15) = 2.54$, $p < .05$, but there was no significant difference between the spacing conditions ($t < 1$).

The skipping rate was affected both by spacing, $F(1,15) = 9.72$, $p = .01$, and text type, $F(1,15) = 7.33$, $p < .05$. Readers skipped over more words in the Kanji–Hiragana (7.2%) than in the Hiragana text (3.6%). They also skipped more words in the unspaced (7.8%) than spaced (2.9%) conditions. This spacing effect was significant separately for both text types: $t(15) = 2.15$, $p < .05$ for Hiragana, and $t(15) = 2.68$, $p < .05$ for Kanji–Hiragana.

In sum, the word-level eye movement parameters demonstrated that word identification is in general faster in Kanji–Hiragana than in Hiragana text. The data also indicated that word recognition is facilitated by interword spacing in Hiragana text but not in Kanji–Hiragana text (not even for the words written in pure Hiragana). Finally, interword spacing decreased the probability of skipping over words in both text types.

3.3. Preferred viewing location (PVL) analyses

To investigate in more detail the spatial aspects of eye movement guidance in Japanese, PVL analyses (i.e., the location of initial fixation in words) were conducted. Due to a small number of short and long words in the sample, only the data for medium length words (3–5 characters) were included in the analyses.

The words were divided into three PVL zones. The 3-character words were divided into three equal zones. The cutpoints for the 4-character words were 1.5 and 2.5 characters from the word beginning; in other words, the first zone comprised the first 1.5 characters, the second zone the area between 1.5 and 2.5 characters, and the third zone comprised the rest. The respective cutpoints for the 5-character words were 2 and 3.5. That is, the 4- and 5-character words had a larger zone in the end of the word. This division is justified as the ends of words receive less initial fixations. It should also be noted that even though Hiragana words tend to be generally longer than Kanji words the number of words included in the analyses was roughly the same for the two types of text.

Fig. 2 illustrates the PVL distribution for the medium length words. As is evident from Fig. 2, the word-initial zone turned out to be the PVL for all other text conditions except for the HSP text. This was confirmed by the ANOVA, which yielded a main effect of word zone, $F(2,30) = 38.08$, $p < .001$; all positions differed from each other ($p < .001$). Word-initial zone received the most initial fixations and the word-final zone the least initial fixations. The interaction between word zone and text type was

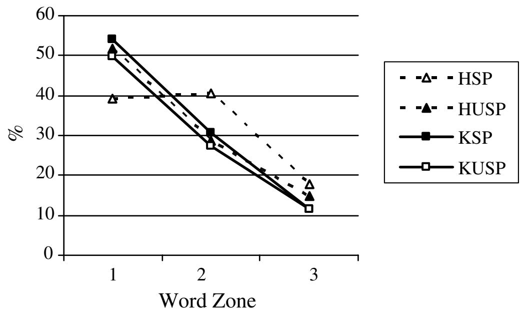

Fig. 2. The distribution of initial landing position (%) for the different text types (HSP, spaced Hiragana; HUSP, unspaced Hiragana; KSP, spaced Kanji–Hiragana; KUSP, unspaced Kanji–Hiragana).

marginally significant, $F(2,30) = 3.51$, $p = .07$, and the interaction between word zone and spacing proved significant, $F(2,30) = 3.33$, $p < .05$. The 3-way interaction between word zone, text type and spacing was significant as well, $F(2,30) = 5.68$, $p < .01$. To examine the 3-way interaction in more detail, we conducted the analysis separately for the Hiragana and Kanji–Hiragana text. The analyses revealed that the interaction between word zone and spacing was significant for Hiragana, $F(2,30) = 8.39$, $p = .001$, but not for Kanji–Hiragana, $F < 1$. Moreover, pairwise *t* tests computed for both text types revealed that the difference between word zones was significant for all pairwise comparisons ($p < .01$) except between the first and second zone in the HSP text.

In sum, spacing had an effect on the initial landing position when reading pure Hiragana text, but not when reading mixed Kanji–Hiragana text. In Hiragana, the presence of interword spacing shifted the PVL toward the word center. This effect resembles that of English: when spaces are available, the PVL moves toward the middle of the word while without spaces it is in the word beginning (Rayner et al., 1998). For mixed Kanji–Hiragana text, the PVL is in the word beginning, and it is not influenced by spacing.

3.4. Optimal viewing position (OVP) analyses

In alphabetical languages, the optimal viewing position (i.e., the initial landing site in a word that results in shortest gaze durations and fewest refixations) is found to be around the word center (e.g., O'Regan et al., 1984). Moreover, the PVL has been found to be close to OVP (PVL is somewhat left from OVP). To estimate the OVP in Japanese, we present data on the relationship between the initial landing zone and time spent fixating a word (i.e., gaze duration and total fixation time). The analyses were conducted only for 11 participants, because five participants did not have data for the word-final zone, particularly in the KSP text. Analogously to the PVL analyses, the OVP analyses were only conducted for the 3–5 character words. The OVP data are presented in Fig. 3.

For the gaze duration, initially landing on the word beginning resulted in the longest gaze durations for all text types (Fig. 3a). This was demonstrated by a main effect of word zone, $F(2,20) = 8.06$, $p < .01$. The first zone differed reliably from the second ($p < .001$) and third ($p < .01$) zone, but the difference between the second and third zone was not significant. The interaction between text type and initial landing zone was not significant, $F(2,20) = 2.70$, $p = .13$. In the separate analyses for Hiragana and mixed Kanji–Hiragana, the main effect of word zone remained significant for both text types and no interactions were observed.

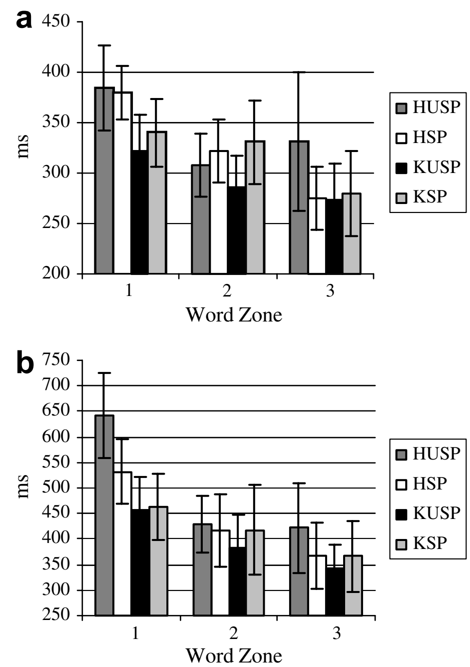

Fig. 3. (a) Gaze duration (in ms) and (b) total fixation time (in ms) per word, as a function of initial landing position and text type (HSP, spaced Hiragana, HUSP, unspaced Hiragana, KSP, spaced Kanji–Hiragana; KUSP, unspaced Kanji–Hiragana. The error bars represent standard deviations.

Total fixation time yielded a similar pattern of results. Word beginning was observed to be least optimal (Fig. 3b). The main effect of word zone was significant, $F(2,20) = 22.98$, $p < .001$. The first zone differed from the second and the third zone ($p < .01$), but the difference between the second and third zones did not prove significant. The results differed from the gaze duration data in that there was a significant interaction between text type and word zone, $F(2,20) = 3.74$, $p < .05$. The interaction reflects the fact that the penalty of initially fixating the word beginning was greater for Hiragana than Kanji–Hiragana.

In sum, the results showed that the first zone was the least optimal site for the initial fixation. Paradoxically, in HUSP, KUSP, and KSP texts this is also the PVL site. We also observed that the penalty for fixating initially on the word beginning was greater for Hiragana than Kanji–Hiragana. Our OVP findings differ from those established for alphabetic script in that we did not find a U-shaped OVP curve where the inner zones are associated with shorter gaze durations than the outer positions. The difference in results is apparent in the word-final zone, which did not result in longer gaze duration in Japanese than the center zone.

4. Discussion

In the present study, effects of interword spacing were studied in reading Japanese. Spacing effects were examined using readers' eye movement patterns as the dependent measure. The main result of the present study is that interword spacing facilitates the reading of syllabic script (Hiragana), but not that of a mixture of ideographic and syllabic characters (Kanji–Hiragana). This conclusion compares favorably with Matsuda (2001) who observed a significant facilitatory spacing effect for Hiragana in the mean sentence reading time and in the mean gaze duration for individual words, while the Kanji–Hiragana text showed no reliable effects with these measures. Matsuda also found a main effect of spacing in the initial landing position: the eyes landed further into the word in the spaced than unspaced text. However, the effect did not interact with script type, which is in contrast to the present study, where the finding was only obtained for Hiragana. All in all, however, the present study replicated the main results of Matsuda using a larger subject sample and a fully counterbalanced design.

The beneficial role of interword spacing established for pure Hiragana compares favorably with analogous findings obtained for alphabetic script (e.g., Rayner et al., 1998). The results obtained for Hiragana are also in line with those observed for Thai, an unspaced alphabetic language. Kohsom and Gobet (1997) found that spaced Thai was slightly faster to read than unspaced Thai. The reliability of the facilitating effects of spacing in Hiragana is strengthened by the fact that, unlike English readers, adult Japanese readers do not read spaced script on a daily basis (i.e., the script that leads to faster reading). On the other hand, it is noteworthy that the spacing effects in Hiragana are considerably smaller than those observed in English. For example, the reading rate for unspaced English is 30% to 50% slower than that for spaced English (Malt & Seamon, 1978; Morris et al., 1990; Pollatsek & Rayner, 1982; Rayner et al., 1998; Spragins et al., 1976), whereas in our study the decrement in reading speed due to lack of spacing was only 12% for Hiragana. An obvious explanation for this difference is that in our case the facilitation is observed for a less familiar reading condition, whereas in English the spaced condition is the normal reading condition and readers are accustomed to encounter words as visually separate units.

The second main finding of the present study is that facilitation due to spacing did not generalize to standard Japanese text that is a mixture of Kanji (ideographic) and Hiragana (syllabic) characters. This observation is in accordance with previous studies of Chinese—a language that contains only ideographic characters. The seminal study of Liu et al. (1974) found that reading of Chinese was not influenced by interword spacing.

We next discuss the significance of our results as regards the nature of spacing effects in Hiragana and the lack of them for Kanji–Hiragana. Rayner et al. (1998) demonstrated that in English interword spacing affects both word identification and eye movement guidance in reading. The facilitation in word identification is reflected in shorter fixation times for words in spaced than unspaced text. This is because fixation times reliably reflect the relative difficulty of word identification during reading (for a review, see Rayner, 1998). Indeed, a spacing effect in fixation times was observed for the pure Hiragana text: Spaced Hiragana was in overall associated with shorter mean fixation duration, and particularly with shorter gaze duration and total fixation time on words than unspaced Hiragana. These findings suggest that interword spaces speed up word identification in Hiragana. On the other hand, in Kanji–Hiragana the only evidence supporting the beneficial role of interword spacing in fixation times was seen in the average fixation duration, which was slightly shorter in spaced than unspaced text, but the word-level fixation time measures did not show any reliable differences between the two spacing conditions. The reason why shorter average fixation durations did not result in shorter gaze durations in the spaced condition was that the spaced condition increased the number of fixations made on a word. All in all, we conclude that word identification in Hiragana is helped by inserting spaces between words, but this is not the case in mixed Kanji–Hiragana script.

The question whether interword spacing is capable of influencing eye movement guidance in reading Japanese was examined by analyzing saccade amplitudes and initial fixation positions in words in the different reading conditions. Perhaps not surprisingly, we observed that adding extra spaces in text lengthened the average saccade amplitude. More interestingly, however, the lengthening of saccade amplitude was significantly greater for pure Hiragana than for Kanji–Hiragana text. This effect is not solely due to adjusting the saccadic amplitude to accommodate it to the extra spaces inserted in the text. This is seen in the PVL analyses. When spaces were inserted in Hiragana, the initial landing site in words shifted toward the word center. Thus, for Hiragana not only word identification but also eye movement guidance is facilitated by interword spacing. This is in line with what Rayner et al. (1998) observed for English.

For Kanji–Hiragana, however, we found no evidence to support the view that spacing would facilitate eye guidance. This becomes apparent from the PVL analyses. PVL was not affected by spacing: In both reading conditions PVL was found to be in the word beginning (see also Kajii et al., 2001), which is typically occupied by a Kanji character. In the Introduction we put forth two opposing predictions regarding the effects of spacing in Kanji–Hiragana, both of which were based on the fact that the visually salient Kanji characters typically appear in the word beginning. The first prediction was that having a space prior to a Kanji would make the word-initial Kanji character even more visually salient, thus attracting an eye movement toward it more often than when no space precedes it. Alternatively, a space preceding a Kanji may facilitate its parafoveal processing, which would lead to more fixations launched toward the word center (i.e., as a result of skipping the word-initial Kanji). Neither prediction was supported by the data, as spacing exerted no effect on PVL. On the other hand, spacing did affect the probability of skipping over words: it was less probable to skip over Kanji–Hiragana words in the spaced than unspaced text. This interference effect due to spacing is probably a result of words being shifted more towards the parafovea, which presumably lowered the probability with which they could be parafoveally recognized and subsequently skipped. Furthermore, spaces between words may restrict attention to a greater extent to single word units by making them appear as separate visual objects in the text.

Finally, we conducted follow-up analyses to determine whether OVP in words would differ between the unspaced and spaced condition. The OVP analyses reveal where in a word readers should initially fixate in order to maximally speed up word identification. These analyses showed that word beginning is the least optimal spot for all four text types: Landing initially in the word beginning resulted in longest gaze durations and total fixation times (see also Kajii et al., 2001). The middle and end zones did not differ from each other. The presence of interword spaces did not modify the OVP effects. On the other hand, a reliable interaction was observed between initial landing position and text type. The penalty of landing initially in the word beginning was greater for the Hiragana text than for the mixed Kanji–Hiragana text.

Despite the fact that the processing of Kanji–Hiragana words was less affected by the initial landing position than pure Hiragana words the word-initial position was still the least optimal position in Kanji–Hiragana. This is a puzzling finding, because Kanjis that express the core meaning of words typically appear word-initially. Therefore, one could assume that it would not be detrimental to initially fixate in the word beginning. A possible explanation of this finding is based on the magnitude of parafoveal processing done in the different trials leading to different initial landing sites. The more parafoveal preprocessing is done of the word prior to its foveal fixation, the further into the word the following saccade will land. Subsequently, less processing time is needed for foveal inspection of this word. Thus, according to this account the OVP data at least in part reflect the magnitude of parafoveal processing.

In conclusion, the present study demonstrates that syllabic script (Hiragana) is processed differently from a mixture of ideographic and syllabic script (Kanji–Hiragana). Signaling word boundaries in the form of interword spacing facilitated both word identification and eye guidance when reading syllabic script, but not when the script contained ideographic characters. Presumably, ideographic characters, frequently appearing in the word beginning, serve as effective segmentation cues to signal word boundaries (see also Kajii et al., 2001). Hence, inserting spaces between words provides no additional help for word identification or eye guidance when reading Kanji–Hiragana text. However, as also pure Hiragana words within Kanji–Hiragana text do not benefit from spacing, there must be more to it. Apparently, Hiragana characters are more easily identified as lexical units when they are surrounded by Kanji characters in unspaced text. In that sense, we may conclude that Kanji characters not only frequently signal word beginnings, but also aid in word segmentation on a more global level.

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