Encoding times for phonograms in English and Japanese readers: Eliminating the time for attention switching

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In our previous letter-matching experiments with native English and Japanese readers employing phonograms as stimuli, physical-matching reaction times (RTs) for Japanese readers were the shortest. We hypothesized that the heavy reliance of Japanese readers on visual codes in processing Kanji dominant texts extends to the processing of phonograms, which leads to short visual encoding times. However, all matching RTs at shorter inter-stimulus intervals (ISIs) were prolonged due to some factor other than encoding, making it impossible to determine encoding times based on matching RTs. Assuming this factor to be the time required for attention switching, we measured simple RTs in order to determine attention-switching times in addition to matching RTs in two letter-matching experiments that manipulated the stimulus onset asynchrony (SOA) by varying first letter presentation times for alphabetic and Japanese phonograms with English and Japanese readers. Simple RTs were found to be longer at shorter SOAs, which is consistent with our assumption. Net matching RTs calculated by eliminating the time required for attention switching indicated that both visual and phonological encodings by native English readers were completed between 100 ms and 300 ms. In contrast, in native Japanese readers, visual encoding was completed within 100 ms, while phonological encoding required the same amount of time as native English readers, which supports our hypothesis.

Key words: visual encoding, phonological encoding, attention switching, native English readers, native Japanese readers

The dominant characters used in Japan are Kanji similar to Chinese characters. Most Kanji are complicated in configuration and have many homophones. Presumably, because of these characteristics, native Japanese readers rely more heavily on visual codes than on phonological codes in processing letters or words written in Kanji (Inoue, 1980).

There is evidence that the heavy reliance on visual codes by people who use Kanji (or Chinese characters) predominantly is not limited to processing Kanji text. Wang, Koda, and Perfetti (2003) investigated the relative reliance on phonological and orthographic processing in English word identification by Korean students, who have an alphabetic first language background, and by Chinese students, who have a non-alphabetic first language background. They found that the Chinese relied more heavily on visual codes than the Koreans. It is probable that this processing reliance on visual codes is even more prominent with native Japanese readers, because most of Japanese Kanji are polyphones while most of Chinese characters are not, and because Japanese text involves far more homophones than Chinese text.
Mizuno, Matsui, and Bellezza (2007) conducted letter-matching experiments to explore differences in the use of visual and phonological codes in processing phonograms between native English and Japanese readers. They used modifications to correct the problematic procedures of Posner, Boies, Eichelman, and Taylor (1969; see Mizuno, Matsui, Bellezza, & Harman, 2005). They presented physically matched (e.g., AA), name matched (Aa), and unmatched (AB) letter pairs with various inter-stimulus intervals (ISIs), and measured the matching reaction times (RTs). The results of Experiment 1a using alphabet letters as stimuli\(^1\) showed that RTs for physical matches and RTs for name matches did not differ for English readers, but physical matching RTs were shorter than name matching RTs for Japanese readers. In Experiment 1b, Japanese phonograms, Hiragana and Katakana, were used as stimuli for Japanese participants and the results were almost the same as those of Experiment 1a. These two experiments suggest that Japanese readers rely more heavily on visual codes than on phonological codes even in processing phonograms. They also suggest that Japanese readers rely more on visual codes than English readers do. These characteristics of Japanese readers are considered to lead to the shorter visual encoding time than their phonological encoding time and than both encoding times of English readers. A different experimental method inhibiting the activation of phonological codes was adopted in Experiment 2a, using alphabet letters as stimuli, and in Experiment 2b, using Hiragana and Katakana as stimuli. The results of these experiments showed that the mean RT for physical matches for English readers in Experiment 2a was shorter than that in Experiment 1a. However, no difference was found in the mean matching RTs for physical matches for Japanese readers between Experiment 1a and Experiment 2a, as well as between Experiment 1b and Experiment 2b, indicating again that Japanese readers rely more heavily on visual codes than English readers do.

However, it is considered impossible to determine precisely the times for visual and phonological encodings for English and Japanese readers based on these data because of the following paradox. There was a common finding in these experiments that RTs for letter pairs of all matching types presented with short ISIs were longer than those presented with longer ISIs. This tendency has also been reported in other research studies (e.g., Parr, 1995; Walker, 1978), but its cause was undetermined. It was because RTs for physical matches and for name matches were supposed to reflect the visual and phonological encoding times only of the second letter, and to be equal at any ISI as long as the code of the first letter did not decay.

This paradox suggests that some other factor than the encoding times of the second letters has some effect on the matching RTs in Mizuno et al. (2007). Therefore, it is considered necessary to specify the cause of this paradox and then to obtain a reliable index eliminating its effect from the matching RTs in order to determine precisely the visual and the phonological encoding times of both groups of readers.

We considered two possible explanations for this paradox. The first was that both visual and phonological encodings were unfinished within the presentation time. Visual and phonological encodings are considered to occur independently and in parallel (Posner, 1978). In many letter-matching experiments, including Posner et al. (1969) and Mizuno et al. (2007), the presentation time of the first letter was set to be 500 ms, which was assumed to be long enough for the first letter to be encoded visually and phonologically. However, if it had taken a little longer than the 500 ms presentation time for both visual and phonological encodings of the first letter to be finished, then the RTs for both matching types at short ISIs could have been prolonged.

The second possible explanation was that the time for the attention switching between the two letters was longer with shorter intervals, which then prolonged the matching RTs. Many participants reported after the experiments that it was more difficult to respond quickly at shorter intervals than at longer intervals. We experienced the letter-matching tasks used in the research and felt that it was harder to respond at shorter intervals than at longer intervals. We consider that this could be because it took time to switch attention from the first letter to the second letter when the second letter was presented immediately after the first letter.

It is well known that when two or more stimuli are presented successively with a short interval, they compete for processing resources (e.g., Potter, Staub, & O’Connor, 2002). It is also well known that detection of a target impairs one’s ability to detect other targets for a relatively short time thereafter (e.g., Pashler, 1998). Various research studies have

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\(^1\) English is a compulsory subject in junior high schools in Japan, and so the Japanese college students are familiar with English alphabet letters and the letter names.
investigated the mechanism of the attention switching (Kinchila, 1992). However, most of the research concerned attention switching between two objects presented at different locations (e.g., Eriksen & Webb, 1989), attention switching between two or more attributes of one stimuli (e.g., Cohen, Dunbar, & McClelland, 1990), factors causing involuntary attention switching between two or more objects (e.g., Folk, Remington, & Johnston, 1992), or dual-task interference and divided attention (e.g., Strayer & Johnston, 2001). There are relatively few studies dealing with the effect of intervals between two stimuli on attention switching.

Most of the research on attention related to the intervals studied the attentional blink. The attentional blink refers to the temporal processing deficit when two targets are presented with short intervals in a RSVP (rapid serial visual presentation) stimulus stream. However, attention switching was studied mostly in terms of the effect of task switching on attention. Task switching involves, for example, changing the processing tasks, categories, or modalities of two stimuli (e.g., Visser, Bishof, & Di Lollo, 1999). There are only a few studies focusing on the effect of different temporal intervals on attention switching. One helpful study is Reeves and Sperling (1986), which explored the time for attention switching using two stimulus streams, and found that it took about 400 ms to switch attention from one stream to another. Other studies are Broadbent and Broadbent (1987), Raymond, Shapiro, and Arnell (1992), and Shapiro, Raymond, and Arnell (1994), which examined the processing deficits of two targets in the RSVP stream and found that the identification of one target interferes with the identification of another target for several hundred milliseconds.

The span of interference might be shorter than several hundred milliseconds in a letter-matching experiment because there is no distracter between the two stimuli, unlike the experiments using the RSVP stimulus stream. However, it was reported that the attentional blink was reduced, but remained even with no distracters (Chun & Potter, 1995), so it is probable that the interfering effect could exist even for a shorter time. If the interfering effect exists for a short time, the time for attention switching with short intervals should be longer than with longer intervals, and this may have prolonged the matching RTs at short intervals in Mizuno et al. (2007).

In this study, we conducted two experiments to determine the cause of RT delay at short intervals in order to eliminate the effect of the cause from matching RTs, and to know precisely the visual and phonological encoding times of phonograms by native English and native Japanese readers. In Experiment 1, alphabet letters were used as stimuli for both the Japanese and English participants. In Experiment 2, Japanese phonograms, Hiragana and Katakana, were used as stimuli for the Japanese participants. Considering the finding of Mizuno et al. (2007), we predicted that the time for visual encoding of either native or nonnative phonograms by Japanese readers would be shorter than the time for their phonological encoding, as well as shorter than the times for visual and phonological encoding of native phonograms by English readers.

We used the following methods. We manipulated SOAs (stimulus onset asynchrony) of the first and the second letters by changing the presentation time of the first letters instead of ISIs since attention should be allocated or switched at the time when the stimulus is presented. In order to know the time for attention switching, simple reaction time (simple RT) was measured, as in Posner, Snyder, and Davidson (1980). Simple reaction time is the time for participants to press a key as soon as they find a stimulus. It reflects the time for the detection of a stimulus, but not the time for allocating attention to a stimulus (Pashler, 1998). When two letters are presented successively, the simple reaction time to the second letter necessarily includes the time for the detection of the first letter. The processing time for the first letter should be constant irrespective of its presentation time and, therefore, the change of the simple RT should reflect the change of the time for switching attention from the first letter to the second letter. Therefore, by measuring simple RTs with various presentation times, we could confirm the validity of the second possible explanation that the time for switching attention caused the longer matching RTs at shorter intervals.

We also measured ordinary matching RTs in the same experimental setting. If both the visual and phonological encodings of the first letter were finished within its presentation time, the matching RTs would reflect the times for the encodings of
only the second letter. On the other hand, if they were not finished within the presentation time, then the matching RTs would get longer because they would include some of the times for the encodings of the first letter. Therefore, if simple RTs do not vary with presentation times, by examining the change of matching RTs for physical-matched letter-pairs and those for name-matched letter-pairs, we could determine the time needed for visual encoding and for phonological encoding respectively to examine the first possible explanation. If simple RTs are longer with relatively shorter presentation times, matching RTs should include the time for attention switching. In this case, we would calculate the net matching RTs by subtracting the simple RTs from the matching RTs, and determine the visual and phonological encoding times based on the net matching RTs for physical-matched letter-pairs and for name-matched letter-pairs.

Experiment 1

Method

Participants. Twenty-four right-handed American undergraduates attending Ohio University in the US and native speakers of English and twenty-four right-handed Japanese undergraduates attending Chubu University in Japan and native speakers of Japanese participated in the experiments in exchange for course credit.

Stimuli and Apparatus. The stimuli were the letters A, B, F, H, M, R in lower or upper case. Stimulus presentation was controlled by the experimental software, SuperLab Pro, Version 2.04 (Cedrus Co.) installed on a personal computer, and responses were recorded by a response box, RB-730 (Cedrus Co.). 90-point letters were presented on a 17 in. (43.18 cm) monitor in 1024×768 pixel graphic mode. The size of the letters on the screen was about 1 in. (2.54 cm) by 1 in. (2.54 cm). Two letters were presented side-by-side at the center of the screen. The mask stimulus was a 1 in. by 1 in. blank square. The response box had seven buttons. The button on the far left was covered with a blue key top, and the button on the far right was covered with a red key top. The other buttons were covered with ordinary white key tops. The far left button was labeled same and the far right button was labeled different during the matching sessions for measuring matching RTs.

For the stimulus pairs, the first letter of each pair was always an upper-case letter; Posner et al. (1969) found in their Experiment 1 that whether the first letter was upper or lower case had no influence on matching RTs. The presentation times of the first letter were set at 100, 300, 500, 700, 900, 1100, 1300, or 1500 ms. The maximum presentation time was set at 1500 ms because the matching RTs for name-matched letter-pairs in Mizuno et al. (2007) varied by 1000 ms ISI and the presentation time of the first letter was 500 ms in that study. Since these eight levels of presentation times were used with six different first letters, there were 48 physically matched pairs, 48 name matched pairs, 48 unmatched pairs of two upper-case letters, and 48 unmatched pairs of an upper-case letter and a lower-case letter. They were 192 pairs in total, which were divided into three blocks of 64 pairs.

Procedure. Participants were tested individually. The experiment consisted of two sessions. The first session was called a simple-response session, in which RTs to respond only to the presentation of the second letter were measured. The second session was called a matching session, in which RTs for matching the two letters (i.e., responses on the buttons for same or different) were measured. All the participants went through a simple-response session first and then a matching session because it was anticipated that the matching judgment could have some influence on their simple responses once they knew the procedure of matching. In each session, the order of the three blocks was counterbalanced among participants, and the order of trials in each block was randomized.

In the simple-response sessions, the hand used to press the response button was switched among the three blocks, and half of the participants used their left hands and pressed the left button first, and the other half used their right hands and pressed the right button first. Before trials, an experimenter told the participants the hand to be used and the key to be pressed, that two letters would be presented on the screen adjacently and successively, and that they should press either a left or a right button with their first finger as soon as the second letter was presented. In the matching sessions, the experimenter showed examples of same pairs and different pairs and instructed participants to compare the two letters, and when they judged them to be the same, to press the button labeled same with the first finger of their left hand and when different, to press the button labeled different with the first finger of their right hand as quickly and correctly as possible.

Participants first went through 12 practice trials, and then performed the experimental trials of three blocks in each session. In each trial, two asterisks were first presented for 300 ms to show the presentation location of the stimulus pairs. After a
1000 ms blank screen, the first letter was presented for one of the eight presentation times. Immediately after that, a mask stimulus was presented in the same location as the first letter, and simultaneously, the second letter was presented adjacently to the mask stimulus. The mask stimulus and the second letter remained present until the participants’ response. After 2000 ms the next trial began.2)

Between the three blocks in each session, two-minute breaks were given. Between the two sessions, a three-minute break was given. The time needed for a participant to finish the two sessions was about 55 minutes.

Results and Discussion

Matching RTs and Error Rates. The results are shown in Figure 1. A three-way (country × matching type × presentation time) mixed analysis of variance was performed on the mean correct matching RTs. The results revealed a main effect of matching type, $F(1, 46) = 40.86$, $p < .001$, $MSE = 5338.38$, a main effect of presentation time, $F(7, 322) = 37.33$, $p < .001$, $MSE = 2267.41$, an interaction of country and matching type, $F(1, 46) = 15.12$, $p < .001$, $MSE = 5338.38$, and a three-way interaction, $F(7, 322) = 2.42$, $p < .05$, $MSE = 1968.30$.

The simple interaction of matching type and presentation time was not significant for native English readers, but was significant for native Japanese readers, $F(7, 322) = 1.11$, ns; $F(7, 322) = 3.16$, $p < .05$, $MSE = 1968.30$. The simple simple effect of matching type for Japanese readers were significant from 100 ms to 1100 ms, $F(7, 368) = 44.30; 20.10; 28.47; 16.36$, so far $p < .001; 5.77$, $p < .05; 9.94; 7.98$, both $p < .005$, and marginally significant for 1500 ms, $F(7, 368) = 3.35$, $p = .068$, $MSE_{pool} = 2389.56$.

These results indicate that matching RTs for physical matches and for name matches did not differ for English readers, while the former was shorter than the latter for Japanese readers. They are analogous to the results of Mizuno et al. (2007), suggesting that Japanese readers depend more on visual codes than on phonological codes, which lead to their shorter visual encoding time than their phonological encoding time.

For the RT differences between presentation times, multiple comparisons were performed for the combined data of the two matching types for
native English readers and for the data of each matching type for native Japanese readers. All multiple comparisons in this article used Ryan’s procedure. The results are shown in Table 1, indicating that matching RTs for the 100 ms presentation time were longer than those for all the other presentation times for both matching types for both groups of readers.

If there were no influence of attention switching, these results could be considered to suggest that both visual and phonological encodings were finished between 100 ms and 300 ms of presentation time. However, this consideration is inconsistent with the suggestion above that the visual encoding time for Japanese readers should be short, and it is highly possible that the time for attention switching prolonged the matching RTs for the shorter presentation time. This possibility will be confirmed later in the analysis of simple RTs and net matching RTs.

Error rates for physical and name matches were 2.8% (SD: 0.024) and 4.4% (0.039) respectively for native English readers, 1.7% (0.023) and 6.8% (0.078) for native Japanese readers. The inverse sign transforms of individuals’ error rates were analyzed by a two-way (country × matching type) mixed analysis of variance. The result showed a main effect of matching type, $F(1,46)=27.66, p<.001, MSE=28.15$, and an interaction of country and matching type, $F(1,46)=128.15, p<.001$. The simple main effect of matching type was significant only for native Japanese readers, $F(1,46)=30.05$, $p<.001$, and the error rates for physical matches and name matches did not differ for native English readers, while the latter was larger than the former.

### Table 1
Results of multiple comparisons of matching RTs between presentation times for native English readers and native Japanese readers using alphabet letters as stimuli in Experiment 1

<table>
<thead>
<tr>
<th>PT Pair</th>
<th>Combined</th>
<th>Physical</th>
<th>Name</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>$m$</td>
<td>$t$</td>
<td>$m$</td>
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<tr>
<td>100–300</td>
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<td>3</td>
</tr>
<tr>
<td>100–500</td>
<td>3</td>
<td>5.79**</td>
<td>5</td>
</tr>
<tr>
<td>100–700</td>
<td>7</td>
<td>5.87**</td>
<td>7</td>
</tr>
<tr>
<td>100–900</td>
<td>5</td>
<td>5.88**</td>
<td>8</td>
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<tr>
<td>100–1100</td>
<td>8</td>
<td>6.07**</td>
<td>4</td>
</tr>
<tr>
<td>100–1300</td>
<td>4</td>
<td>6.09**</td>
<td>6</td>
</tr>
<tr>
<td>100–1500</td>
<td>2</td>
<td>6.44**</td>
<td>2</td>
</tr>
<tr>
<td>500–900</td>
<td>7</td>
<td>3.42*</td>
<td>6</td>
</tr>
<tr>
<td>500–1500</td>
<td>6</td>
<td>3.04*</td>
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</tbody>
</table>

Note. Only significant values are listed. PT: presentation time (ms). For English readers, $MSE=2267.41$, and for Japanese readers, $MSE_{pool}=2117.85$. * $p<.05$, ** $p<.01$.

![Figure 2](image_url) Mean simple RTs as a function of presentation time of the first letter for native English readers and for native Japanese readers using alphabet letters as stimuli in Experiment 1.
These results show that there was no trade-off between matching RTs and error rates. They also indicate that Japanese readers sometimes make their responses based on visual codes even for name matches, suggesting the larger dependence of Japanese readers on visual codes in processing nonnative phonograms than on phonological codes just as suggested by the results of the analysis of matching RT.

**Simple RTs.** The simple RTs were analyzed to see whether the changes in matching RTs as a function of presentation time were caused either by the time required for the completion of encoding of the first letter or by the time for attention switching. The results are shown in Figure 2. A two-way (country × presentation time) mixed analysis of variance was performed on the mean simple RTs. The results showed that only the main effect of presentation time was significant, $F(7, 322) = 149.12$, $p < .001$, $MSE = 191.08$. Multiple comparisons were then performed, which showed that simple RTs became shorter and then became constant as the presentation time increased (Table 2).

These results suggest that time for attention switching might have prolonged the matching RTs at short ISIs. In the next section, therefore, net matching RTs will be calculated by subtracting simple RTs from matching RTs and be analyzed in order to determine precisely the times of visual and phonological encodings.

**Net Matching RTs.** The net matching RTs are shown in Figure 3. Country differences had already been analyzed for matching RTs and, therefore, were not included in the analysis of net matching RTs. In the analysis of matching RTs, the difference due to matching type was not found for native English readers but was found for native Japanese readers. Therefore, the net matching RTs of native English readers were analyzed by a one-way (presentation time) repeated measures
For native Japanese readers, the main effect of presentation time was significant, $F(7, 161) = 2.49$, $p < .05$, $MSE = 1335.77$, and multiple comparisons revealed that the net matching RTs for both matching types became shorter than $100$ ms and $300$ ms, then became constant, and then became as long as the RTs for $100$ ms after $1300$ ms (Table 3, left).

For native Japanese readers, the main effects of matching type, $F(1, 23) = 34.87$, $p < .001$, $MSE = 8088.6$, presentation time, $F(7, 161) = 2.53$, $p < .05$, $MSE = 2285.1$, and the interaction of matching type and presentation time, $F(7, 161) = 3.13$, $p < .005$, $MSE = 1988.7$, were significant. Since the interaction was significant, their simple main effects were examined. The simple main effects of matching type were significant from $100$ ms to $1100$ ms, $F(1, 184) = 38.48; 17.46; 24.73; 14.21$, so far $p < .001; 5.01$, $p < .05; 8.63$, $p < .005; 6.94$, $p < .01$, and marginally significant for $1500$ ms, $F(1, 184) = 2.90$, $p = .09$, $MSE = 2751.18$, indicating that the net matching RTs for name matches were longer than those for physical matches. The simple main effect of presentation time was significant only for name matches, $F(7, 322) = 4.34$, $p < .001$, $MSEpool = 2136.87$. Multiple comparisons revealed that the net matching RTs for name matches for $100$ ms were longer than those for all the other presentation times (Table 3, right).

These results indicate that for native English readers both the visual and the phonological encoding of the first letter are finished between $100$ ms and $300$ ms after the presentation. For native Japanese readers, the phonological encoding is finished between $100$ ms and $300$ ms and the visual encoding is finished within $100$ ms. These findings invalidate the first explanation that the encoding of the first letter was not finished within $500$ ms of presentation time. They are consistent with the results of Mizuno et al. (2007) where the mean matching RT for physical matches of Japanese readers was shorter not only than their mean matching RT for name matches, but also was shorter than the mean RTs for both physical and name matches of English readers. This is also evidence that matching RTs include the time for attention switching as described in the analysis of matching RTs, and that it is necessary to eliminate the time from matching RTs to determine precisely the encoding times.

All of these results, considering the analytical result of error rates, suggest that English readers depend equally on visual and phonological codes, which makes the time for their visual and phonological encodings equal, and that Japanese readers depend more on visual codes than on phonological codes, which makes the time for their visual encoding shorter than that for their phonological encoding.

However, as described in the Introduction, it may be that the encoding times for native letters by Japanese readers are different from those for non-native letters. Experiment 2, therefore, replicates Experiment 1 with Japanese participants using their native letters as stimuli.

### Experiment 2

#### Method

**Participants.** Twenty-four right-handed Japanese undergraduates attending Chubu University in Japan and native speakers of Japanese participated in the experiments in exchange for course credit. None of these students participated in Experiment 1.

**Stimuli and Apparatus.** The apparatus was the same as in Experiment 1. The stimuli were six letters of a Japanese phonogram, Hiragana, あ, い, す, て, は, ら, and six letters with corresponding sounds of another Japanese phonogram, Katakana, ァ, イ, ス, テ, ホ, ラ. There were $48$ each of physically matched pairs like “あお”, name matched pairs like “あァ”, unmatched pairs of two Hiragana like “あい”, and unmatched pairs of Hiragana and Katakana like “アイ”. Three blocks...
were constructed in the same way as in Experiment 1.

Procedure. The procedure was the same as Experiment 1.

Results and Discussion

Matching RTs and Error Rates. The results are shown in Figure 4. A two-way (matching type × presentation time) repeated measures analysis of variance was performed on the mean correct RTs. The results showed significant main effects of matching type, \(F(1, 23) = 48.81, p < .001, \) \(MSE = 2062.78\), presentation time, \(F(7, 161) = 21.91, p < .001, \) \(MSE = 1760.29\), and their interaction, \(F(7, 161) = 2.16, p < .05, MSE = 1340.93\).

The simple main effects of matching type were significant for presentation times from 100 ms to 500 ms, \(F(1, 184) = 32.62; 12.34; 12.39\), so far \(p < .001\), for 1100 ms and 1300 ms, \(F(1, 184) = 12.90, p < .001; 6.24, p < .05, MSE = 1431.16\). RTs for physical matches were shorter than those for name matches. These results are quite similar to the results for the Japanese readers with English alphabet letter stimuli in Experiment 1.

The simple main effect of presentation time was significant both for physical matches, \(F(7, 322) = 7.83, p < .001\), and for name matches, \(F(7, 322) = 18.90, p < .001, MSE_{pool} = 1550.61\). Multiple comparisons revealed that the matching RTs for the 100 ms presentation time for both matching types were longer than those for all the other presentation times (Table 4). These results are quite similar to the results for the Japanese readers in Experiment 1.

Since the results of Experiment 1 have already suggested that the time for attention switching prolongs the matching RTs for the shorter presentation time, it is necessary to know the change of net matching RTs as a function of presentation time in order to determine the time for encodings. Therefore, the effect of presentation time will be discussed later in the analysis of the net matching RTs.

Error rates for physical and name matches were 2.0 (SD: 0.026) and 4.9 (0.037) respectively. The inverse sign transforms of individuals’ error rates were analyzed by a one-way (matching type) repeated measures analysis of variance. The result showed an effect of matching type, \(F(1, 23) = 25.57, p < .001, MSE = 19.06, \) indicating that error rate for name matches was larger than that for physical match.

This result again shows that there was no

![Figure 4. Mean matching RTs for two matching types as a function of presentation time of the first letter for native Japanese readers using Japanese letters as stimuli in Experiment 2.](image)

![Figure 5. Mean simple RTs as a function of presentation time of the first letter for native Japanese readers using Japanese letters as stimuli in Experiment 2.](image)

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Note. Only significant values are listed.

PT: presentation time (ms).

** \( p < .01 \).
Results of multiple comparisons of simple RTs between presentation times for native Japanese readers using Japanese letters as stimuli in Experiment 2

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<td>13.21**</td>
<td>5</td>
</tr>
<tr>
<td>1300</td>
<td>7</td>
<td>13.52**</td>
<td>6</td>
</tr>
<tr>
<td>1500</td>
<td>8</td>
<td>13.91**</td>
<td>7</td>
</tr>
</tbody>
</table>

Note. Only significant values are listed. PT: presentation time (ms).

* $p < .05$. ** $p < .01$.

trade-off between matching RTs and error rates. This result indicates that Japanese readers sometimes make their responses based on visual codes even for name matches just as indicated by the analytical result of error rates in Experiment 1, suggesting the large dependence of Japanese readers on visual codes in processing either native or nonnative phonograms, which makes their visual encoding time short.

**Simple RTs.** The results are shown in Figure 5. A one-way (presentation time) repeated measures analysis of variance was carried out on the mean simple RTs. The results show that the main effect of presentation time was significant, $F(7, 161)= 41.15$, $p < .001$, $MSE= 226.51$, and multiple comparisons revealed that simple RTs decreased by several hundred milliseconds and then became constant (Table 5). These results for simple RTs, similar to Experiment 1, suggest that the time for attention switching for the shorter presentation times makes the comparable matching RTs longer.

**Net Matching RTs.** The results are shown in Figure 6. A two-way (matching type × presentation time) repeated measures analysis of variance was performed on the mean net matching RTs. As the differences due to matching type have already been reported in the analysis of the matching RTs, only the results related to the presentation time are reported. The main effect of presentation time was significant, $F(7, 161)= 2.09$, $p < .05$, $MSE= 2186.01$, and the interaction of matching type and presentation time was significant, $F(7, 161)= 2.16$, $p < .05$, $MSE= 1340.93$. The simple effect of presentation time was significant only for name matches, $F(7, 322)= 3.47$, $p < .005$, $MSE_{pool}= 1763.47$.
Multiple comparisons revealed that the net matching RT for name matches at 100 ms was significantly longer than the net matching RTs for all the other presentation times (Table 6).

These results indicate that for Japanese readers the visual encoding of their native Japanese letters is finished within 100 ms, and the phonological encoding is finished between 100 ms and 300 ms, which is analogous to the results for the Japanese participants in Experiment 1 with alphabet letters. Taking the results of error rates into account, all of the results suggest, as predicted, that Japanese readers rely more heavily on visual codes than on phonological code in processing either native or nonnative phonograms, and that Japanese readers do so more than English readers do, which makes their visual encoding time of phonograms in general much shorter than their phonological encoding time and than both encoding times of English readers.

General Discussion

Two experiments showed that native Japanese readers depend heavily on visual codes even in processing phonograms, either native or nonnative, which makes their visual encoding time extremely short. They revealed that the visual and the phonological encodings by English readers in processing phonograms are finished between 100 ms and 300 ms while the phonological encoding by Japanese readers is finished between 100 ms and 300 ms but their visual encoding is finished much earlier, within 100 ms, in processing either native or nonnative phonograms. These findings validate our hypothesis.

As for encoding times for native Japanese readers, Fujimaki and Hayakawa (2005) measured times for visual, phonological, and semantic processing of letters using MEG and fMRI. They found that activation of the brain area related to visual encoding began a little before 100 ms and those brain areas related to phonological and semantic encodings were activated at around 200 ms. This is consistent with the results of our present study.

The predominant letters for Japanese readers are ideograms (Kanji), which are polyphones and have many homophones. Therefore, Japanese readers rely more on visual codes than on phonological codes (e.g., Goryo, 1987), and this processing characteristic may have made their visual encoding times shorter than their phonological encoding times. It is interesting that this research, like the findings of Wang et al. (2003) described in the Introduction, suggests that this processing characteristic of the predominant letters extends to the processing of native and nonnative phonograms.

It is highly probable that the processing of predominant letters of other countries should have large influence on that of letters other than native letters. For example, the visual encoding time of letters of native Korean readers may not be shorter than the phonological encoding time because Hangul characters are phonograms. Visual and phonological encoding times of native Chinese readers may not differ as much as for native Japanese readers because most Chinese characters are not polyphones like Japanese Kanji. It is now considered necessary and interesting to investigate the influence of the characteristics of the predominant letters on general letter encoding times.

In addition, this research revealed that the longer matching RTs at shorter SOAs were caused by attention switching from the first letters to the second letters. This means that ordinary matching RTs include the time for attention switching. Actually, the change of matching RTs as a function of presentation time in Experiment 1 and Experiment 2 indicated that the visual encoding of Japanese readers is also finished between 100 ms and 300 ms just as the phonological encoding of Japanese readers and the visual and the phonological encodings of English readers are. However, this finding is inconsistent with the fact that the matching RTs for physical match of Japanese readers were shorter than the others. Therefore, it is necessary to eliminate the time for attention switching from matching RTs in order to determine precisely the time for visual and phonological encodings. The net matching RTs calculated by subtracting the times for attention switching, namely, simple RTs, from matching RTs indicated that visual encoding time for Japanese readers is shorter than the others. This finding is consistent with the fact described above.

In this study, however, the presentation times of the first letters were manipulated. It is still uncertain if the same results would be obtained in ordinary letter-matching experiments manipulating the ISIs between two letters, as in Posner et al. (1969) and Mizuno et al. (2007). Therefore, it would be necessary to measure both simple RTs and matching RTs in ordinary letter-matching experiments to confirm these results.

References


From detection to identification: Response


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