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## Selective impairment of On-reading (Chinese-style pronunciation) in alexia with agraphia for kanji due to subcortical hemorrhage in the left posterior middle temporal gyrus

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### ABSTRACT

We report a patient with alexia with agraphia for kanji after hemorrhage in the left posterior middle temporal gyrus. The results of single-character kanji reading and two-character *on*- (Chinese-style pronunciation), *kun*- (native Japanese pronunciation), and Jukujikun (irregular *kun*-) reading word tests revealed that the patient could not read kanji characters with *on*-reading but read the characters with *kun*-reading. We consider that this *on*-reading alexia was caused by disconnection between the posterior inferior temporal cortex (orthographic lexicon) and the posterior superior temporal gyrus (phonological lexicon), and preserved *kun*- and Jukujikun-reading was realized by bypassing the orthography-to-phonology route by the semantic route.

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### KEYWORDS

*On*-reading; *kun*-reading; *on*-reading alexia; kanji; middle temporal gyrus

### Introduction

Nonaphasic alexia with agraphia occurs following damage to the left angular gyrus (plus the lateral occipital gyri) and the left posterior inferior temporal cortex (Brodmann area 37) (Sakurai, 2011). Because of the two distinct writing systems in the Japanese language, kanji (Japanese morphograms of Chinese origin) and kana (Japanese phonetic syllabary writing), there may be instances where Japanese patients with alexia with agraphia show dissociative disturbances between kanji and kana. For example, kana reading was prominently disturbed in an angular gyrus lesion, whereas kanji reading and writing were selectively impaired in a lesion of the posterior inferior temporal cortex (Iwata, 1986). Moreover, the combination of kana alexia and kanji agraphia caused by damage to the occipital and inferior temporal gyri was reported (Mochizuki & Ohtomo, 1988).

In angular alexia with agraphia, reading is more impaired in kana than in kanji, whereas writing is more impaired in kanji than in kana (Kawamura, 1990; Miyake & Tanaka, 1992). Neuropsychologically, kana alexia encompasses a letter identification deficit and a grapheme–phoneme conversion disorder, whereas kanji agraphia corresponds to lexical agraphia (selective impairment of irregular word spelling) (Ullrich & Roeltgen, 2011) in European countries.

In alexia with agraphia due to a posterior inferior temporal cortex lesion, kanji reading and writing are predominantly impaired, although kana reading and writing are more or less disturbed. We designated this symptom as orthographic alexia with agraphia in the sense that errors are derived mainly from damaged visual word forms (Sakurai, 2004).

There are two ways of reading kanji: *on*-reading (Chinese-style pronunciation at the time of borrowing) and *kun*-reading

(native Japanese pronunciation). A kanji character usually has multiple *on*- and *kun*-readings. Both *on*-reading and *kun*-reading convey the phonetic value and meaning. However, *on*-reading has many homophones. For example, the *on*-reading /shin/ is shared with 29 out of 2136 daily-use kanji characters ([https://www.bunka.go.jp/kokugo\\_nihongo/sisaku/joho/joho/kijun/naikaku/kanji/joyokanjisakuin/](https://www.bunka.go.jp/kokugo_nihongo/sisaku/joho/joho/kijun/naikaku/kanji/joyokanjisakuin/)). Therefore, it is difficult to identify a kanji only using a single *on*-reading; a kanji can be identified using *kun*-reading or the context. In this sense, *on*-reading, which originally means “pronunciation of a word” in Japanese, primarily conveys the phonetic value according to the Chinese pronunciation, and thus should be called phonetic reading. In contrast, *kun*-reading has no or at most two homophones with different accents. Thus, it is easy to identify a kanji using a single *kun*-reading. For this reason, *kun*-reading, which originally means “interpretation or meaning of a word” in Japanese, has direct access to the meaning of kanji, and thus should be called semantic reading.

This dual reading system can cause *on*–*kun* distinction in some brain-damaged patients. We found that *kun*-reading was predominantly impaired in patients with semantic dementia. When reading a kanji character, the patients read it first with *on*-reading irrespective of the context and did not recall *kun*-reading (Y. Sakurai et al., 2006a). This *on*-preceding and *kun*-deletion phenomenon is characteristic of Japanese semantic dementia. Furthermore, patients have difficulty reading specific-reading words called Jukujikun. Jukujikun is the semantic assignment of Chinese characters to native Japanese words (Kindaichi, 1988): e.g., 眼鏡 ([megane], eye glasses) consists of two kanji characters 眼 ([gaN] (*on*-reading), [me] (*kun*-reading), eye) and 鏡 ([kyou] (*on*-reading), [kagami] (*kun*-reading)), mirror). The pronunciation [megane] is unpredictable from those

of the two constituent characters. Thus, Jukujikun is regarded as irregular *kun*-reading (Kess & Miyamoto, 1999).

Although *kun*- and Jukujikun-reading are predominantly impaired in patients with semantic dementia, it is not known whether there is a clinical state wherein *on*-reading is predominantly impaired. We report a patient who showed pronounced *on*-reading impairment with relative preservation of *kun*- and Jukujikun-reading following hemorrhage in the left posterior middle temporal gyrus and discuss the double dissociation of *on*- and *kun*-reading.

## Case report

During hospitalization for treatment of a fever of unknown origin, a right-handed, 66-year-old woman with 14 years of education became aware that she could not recall her name. Neurological examination showed right lower homonymous quadrantanopsia, mild anomia, and alexia with agraphia. A brain computed tomography (CT) scan revealed subcortical hemorrhage in the left posterior middle temporal gyrus and part of the angular gyrus. Systemic workup revealed ovarian carcinoma with metastatic peritoneal dissemination. Magnetic resonance imaging (MRI) performed 30 days after disease onset revealed a high-intensity area in the posterior half of the left middle temporal gyrus that extended to the angular gyrus on T1-weighted and fluid-attenuated inversion recovery (FLAIR) images (Figure 1).

## Neuropsychological assessment

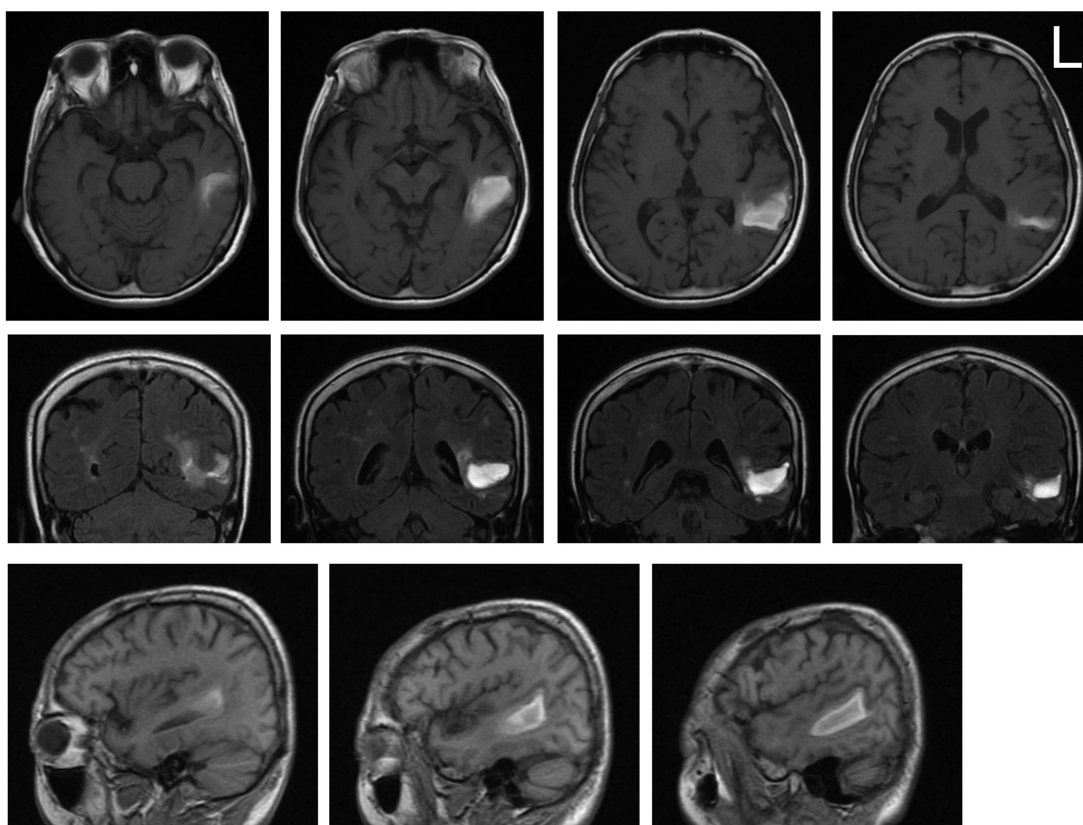
The patient underwent the following neuropsychological assessments from disease onset to 12 months later. Written informed consent was obtained from the patient.

## Standard neuropsychological tests

In the Wechsler Adult Intelligence Scale-III (WAIS-III) administered 7 months after disease onset, her general intelligence was within the normal range (Table 1). In the Western Aphasia Battery (WAB, Japanese edition) 3 months after disease onset, minimal anomia and agraphia of kanji were noted. Although with some verbal paralexia, the reading comprehension of mixed kanji and kana sentences was intact. In the Test of Lexical Processing in Aphasia (TLPA) (I. Fujita et al., 2001) 4 months after disease onset, lexical decision (to detect whether a two-character kanji sequence was a real word or not) was nearly normal (93% [149/160] correct).

## Special neuropsychological tests

To determine the characteristics of alexia and agraphia, we administered three kinds of tests during the follow-up period: reading and writing test of single-character kanji and kana transcriptions, *on*-*kun* reading test, and multiple character



**Figure 1.** Magnetic resonance images 30 days after disease onset. T1-weighted axial (upper) and sagittal (lower) images and fluid-attenuated inversion recovery (FLAIR) coronal images (middle) indicate a subcortical high-intensity area in the left posterior half of the middle temporal gyrus.

**Table 1.** Patient's scores on standard neuropsychological tests.

	Patient	Controls <sup>a</sup> Mean (SD)
WAIS-III (7 months after disease onset)		
Verbal IQ	90	100 (15)
Performance IQ	117	100 (15)
Working memory	90	100 (15)
Processing speed	92	100 (15)
WAB (3 months after disease onset)		
Spontaneous speech		
Information content (/10)	9	9.7 (0.6)
Fluency (/10)	10	10.0 (0.0)
Naming total (/10)	8.2	9.5 (0.6)
Object naming (/60)	54	59.2 (2.4)
Repetition (/10)	8.4	9.87 (0.3)
Comprehension total (/10)	9.6	9.8 (0.1)
Reading total (/10)	8.7	9.5 (0.8)
Comprehension of sentences (/40)	40	37.4 (5.3)
Kanji printed word-object matching (/3)	3	3.0 (0.0)
Kana printed word-object matching (/3)	3	3.0 (0.0)
Writing total (/10)	9.7	9.6 (1.0)
Kanji writing (/6)	2.5	5.3 (1.5)
Kana writing (/6)	6	5.7 (1.0)
Calculation (/24)	24	23.1 (2.3)
Praxis (/60)	58	59.8 (0.7)
TLPA (4 months after disease onset)		
Lexical decision of two-character kanji		
High-frequency, high-imageable words (/20)	20	20.00 (0.00)
High-frequency, low-imageable words (/20)	19	19.92 (0.35)
Low-frequency, high-imageable words (/20)	19	19.96 (0.20)
Low-frequency, low-imageable words (/20)	15	18.83 (2.08)
Nonwords (/80)	76	77.31 (3.76)
Total (/160)	149	156.10 (6.97)

<sup>a</sup>Data for the normal controls are based on the manuals for WASI-III (Japanese edition) (K. Fujita et al., 2006), WAB (Japanese edition) (Sugishita, 1986), and TLPA (I. Fujita et al., 2001).

WAIS-III, Wechsler Adult Intelligence Scale-III; WAB, Western Aphasia Battery; TLPA, Test of Lexical Processing in Aphasia.

kana reading tests (Table 2). The patient's responses and time for reading or writing were recorded.

### Reading and writing test of 100 single-character kanji and kana transcriptions (Table 2, I)

All of the kanji characters used in the test are taught in the first 3 years of primary school in Japan (Y. Sakurai et al., 2000b). Kana reading and writing was perfect, whereas kanji writing was severely impaired at 3 months after disease onset. Most of the kanji writing errors were no responses due to a character recall deficit. Although the score for kanji reading was within the normal range, the patient spent much time in reading kanji.

Of note is that the patient did not recall *on*-reading of some kanji characters, even though she could recall the *kun*-reading. In the second follow-up examination, she was asked to read kanji characters with *on*-reading only or *kun*-reading only for a total of 98 kanji characters (two characters that are read solely with *on*-reading were excluded from the analysis). The result showed that *on*-reading was selectively impaired compared with *kun*-reading ( $P < 0.0001$  using Fisher's exact method). All the characters that were not read with *on*-reading were read with *kun*-reading. Occasionally, she read the character first with *kun*-reading and then searched for the *on*-reading associated with the *kun*-reading. Also, she tried to associate two-character *on-on* reading words that contained the character, and then recalled *on*-reading (e.g., 白 [shiroi], *kun*-reading, white → 紅白 [kou-haku], *on-on* reading, red and white → 白 [haku], *on*-reading).

Next, to investigate the effects of visual complexity (measured by the number of writing stroke sequences), concreteness (Kitao et al., 1977), familiarity (Kitao et al., 1977), frequency (Amano & Kondo, 2000), and imageability (Sakuma et al., 2008), we divided the test characters into two groups (above or under the median)—a more complex, concrete, familiar, or frequent group and a less complex, concrete, familiar, or frequent group—and compared the number of correct responses between the two groups in the follow-up test 5 months after disease onset. In the kanji *on*-reading only task, complexity ( $P = 0.04$ ), frequency ( $P = 0.001$ ), and familiarity ( $P = 0.006$ ) were significant using Fisher's exact method. In the kanji writing task, complexity ( $P < 0.0001$ ), frequency ( $P = 0.0048$ ), and familiarity ( $P < 0.0001$ ) were significant using Fisher's exact method. These results suggested that visual complexity, frequency, and familiarity influenced the performance of kanji *on*-reading and writing.

### *On-kun* reading test of *on-on* reading, *kun-kun* reading, and specific- (Jukujikun) reading of two-character kanji words (Table 2, II)

The tests consisted of 100 *on-on* reading words (e.g., 海岸 [kai-gan], seashore), *kun-kun* reading words (e.g., 野原 [no-hara], field), and 60 specific-reading words called Jukujikun (see the Introduction for an example). All of the kanji characters tested here are taught within nine grade levels of compulsory education in Japan. The results showed that *on*-reading was significantly more impaired than *kun*-reading ( $P < 0.0001$  using Fisher's exact method) and specific-reading ( $P = 0.003$  using Fisher's exact method), and there was no difference in the percentage of correct scores between *kun*-reading and specific-reading.

The frequency and familiarity (Amano & Kondo, 2000) of these word groups were different (mean logarithmic frequency [SD]: *on*-reading, 3.47 [0.84]; *kun*-reading, 2.64 [0.87]; specific-reading, 2.98 [0.74]; mean familiarity [SD] assessed by a seven-rating scale: *on*-reading, 5.94 [0.43]; *kun*-reading, 5.62 [0.59]; specific-reading, 5.78 [0.49]). We therefore reduced the number of stimulus items of the *on*-reading and *kun*-reading words from 100 to 60 so that the mean and SD would be close to those of the specific-reading (mean logarithmic frequency [SD]: *on*-reading, 2.97 [0.69]; *kun*-reading, 2.95 [0.75]; mean familiarity [SD]: *on*-reading, 5.85 [0.49]; *kun*-reading, 5.72 [0.50]). In this condition, as well, the inferiority of *on*-reading to *kun*-reading or specific-reading remained consistent, and the score for *kun*-reading was not different from that for specific-reading.

Errors included no response (22 out of a total of 42 errors [52%]) and phonological errors (phonemic paralexia, 9/42 [21%]) in the *on*-reading test, no response (6 out of a total of 15 errors) and phonological errors (6/15) in the *kun*-reading test, and *kun*-substitution (changing the specific-reading to *kun*-reading) (5 out of a total of 11 errors) in the specific-reading test.

### Reading test of kana single characters, three-character kana words and nonwords, and five-character kana words and nonwords (Table 2, III) (Y. Sakurai et al., 2010)

Single-character kana were 46 letters of the kana syllabary. High-familiarity three-character kana words (mean, 5.98 on a seven-



**Table 2.** Patient's scores on special neuropsychological tests.

	3 months	5 months	14 months	Controls <sup>a</sup> Mean score (SD) Mean time (SD)
<b>I. Reading and writing (100 single-character kanji and kana transcription), raw score and time (percentile)</b>				
Kanji reading (/100)	97 (2)	96 (1) 4 min 50 s (> 99)	99 (8) 3 min 20 s (> 99)	99.6 (1.2) 1 min 32 s (32 s)
Kanji <i>on</i> -reading (/98)	n.d.	70 (71.4%) 23 min 9 s	78 (79.5%) 17 min 25 s	n.d.
Kanji <i>kun</i> -reading (/98)	n.d.	96 (98%) 4 min 56 s	98 (100%) 4 min 5 s	n.d.
Kana reading (/100)	100 (99)	n.d.	100 (99)	99.6 (0.5)
Kanji writing (/100)	29 (< 1)	48 (< 1) 24 min 29 s (> 99)	50 (< 1) 19 min 12 s (> 99)	1 min 13 s (24 s) 95.9 (3.0)
Kana writing (/100)	100 (> 39)	n.d.	100 (> 39) 5 min 52 s (4)	10 min 11 s (136 s) 99.3 (0.9) 8 min 7 s (107 s)
<b>II. <i>On-kun</i> reading test, raw score and time (percentile)</b>				
<i>On</i> -reading (/100)		58 (< 1) 9 min 46 s (> 99)	73 (< 1) 10 min 27 s (> 99)	98.6 (1.7) 1 min 26 s (26 s)
<i>On</i> -reading (/60)		31 (52%) (< 1)	40 (67%) (< 1)	58.9 (1.3)
<i>Kun</i> -reading (/100)		85 (< 1) 12 min 20 s (> 99)	92 (1) 8 min 25 s (> 99)	97.3 (2.5) 1 min 58 s (40 s)
<i>Kun</i> -reading (/60)		52 (87%) (< 1)	56 (93%) (10)	58.5 (1.7)
Specific-reading (/60)		49 (82%) (< 1) 8 min (> 99)	45 (75%) (< 1) 6 min 53 s (> 99)	57.6 (3.2) 1 min 17 s (30 s)
<b>III. Reading (single-, three-, and five-character kana words and nonwords), correct responses and time (percentile)</b>				
Single-character kana (/46)		46 (> 19) 44 s <sup>b</sup> (> 99)		45.7 (0.6) 24 s (4 s)
Three-character kana words (hf) (/100)		96 (5) 3 min 8 s <sup>b</sup> (> 99)		98.3 (1.6) 2 min 1 s (37 s)
Three-character kana words (lf) (/100)		99 (67–80) 5 min 26 s (> 99)		96.6 (2.0) 2 min 28 s (41 s)
Three-character kana nonwords (/100)		97 (10–50) 5 min 26 s (> 99)		97.8 (1.3) 2 min 1 s (37 s)
Five-character kana words (/50)		50 (> 49) 2 min 32 s <sup>b</sup> (> 99)		49.5 (0.5) 1 min 24 s (32 s)
Five-character kana nonwords (/50)		47 (> 39) 4 min 25 s (> 99)		47.0 (2.1) 2 min 16 s (33 s)

<sup>a</sup>Healthy controls: reading and writing (I),  $n = 11$  (mean, 68 years old); *on-kun* reading (II),  $n = 10$  (mean, 71 years old); reading (III),  $n = 11$  (mean, 73 years old); all with 9 or more years of education and no past history of neurologic illness.

<sup>b</sup>The mean time for reading kana by the patient (and healthy controls) was as follows: single-character, 0.96 (0.53) s/character; three-character words, 1.88 (1.22) s/word; and five-character words, 3.04 (1.70) s/word.

hf, high familiarity; lf, low familiarity; n.d., not done.

point rating scale) and five-character kana words were selected from research reports (Amano & Kondo, 2000; T. Fujita et al., 1991), and three-character and five-character nonwords were made by changing the sequential order of kana characters, e.g., きのう ([kinou], yesterday) → うのき ([unoki], nonword). Low-familiarity kana words (mean, 4.20 on a seven-point rating scale) (Amano & Kondo, 2000) were also provided. The results showed that kana reading was nearly normal, and there were no lexicality or familiarity effects. However, the patient read three-character low-familiarity words and nonwords and five-character nonwords in a letter-by-letter manner, and a minor degree of word length effect was observed (Table 2, footnote b).

### Recovery of function over time

Although *on*-reading alexia and lexical agraphia for kanji recovered partially over the course of the disease, the percentage of correct responses remained at 80% in kanji *on*-reading and 50% in kanji writing 14 months after disease onset.

### Discussion

The patient presented with alexia with agraphia for kanji, anomia, and acalculia after cerebral hemorrhage in the posterior half of the left middle temporal gyrus extending to the angular gyrus. Although kana words were read correctly, letter-by-letter reading and a minor degree of word length effect were observed. Characteristically, alexia of kanji was more pronounced in *on*-reading: she read some kanji characters with *kun*-reading, but could not recall *on*-reading. Agraphia of kanji was due to a character recall deficit.

It is clear from the results of two reading tests that *on*-reading was selectively impaired even though *kun*-reading was relatively preserved. In the 100 single-character kanji reading test, the patient could not recall *on*-reading of 27 kanji characters that she could read with *kun*-reading. She was aware that she was able to recall *on*-reading when she first read the kanji with *kun*-reading or found an associated two-character *on-on* reading kanji word that contained the target character. The *on-kun* reading test further demonstrated that

she was poor at reading *on*-reading words, whereas she read *kun*-reading and specific-reading words fairly well.

This result, together with our previous finding that *kun*-reading is preferentially disturbed in semantic dementia (Y. Sakurai et al., 2006a), supports a double dissociation between *on*-reading and *kun*-reading.

### Mechanism of on-reading alexia

From a neuropsychological perspective (Beeson & Rapcsak, 2010), reading is processed through two pathways: the sublexical phoneme-to-grapheme conversion route and the lexical whole-word route. On the basis of the previous case studies (Y. Sakurai et al., 2010, 2000b; Y. Sakurai, Terao et al., 2008; Y. Sakurai et al., 2006a, 2006b; Sasanuma, 1975) (Figure 2(a)) and our positron emission tomography studies, we proposed an anatomically constrained model of reading (Sakurai, 2004; Y. Sakurai, Momose, et al., 2000a) (Figure 2(b)). In this model, visual information of words and letters is transmitted either to the posterior superior temporal gyrus, the site of the phonological lexicon (P), via the lateral occipital gyri and the deep perisylvian temporoparietal cortex (a phonological route that enables successive grapheme-phoneme conversion), or to the posterior inferior temporal cortex (more precisely, mid-fusiform/posterior inferior temporal gyri), the site of the orthographic lexicon (O) or so-called visual word form area (Cohen et al., 2000), via the fusiform gyrus (an orthographic route that enables holistic whole-word recognition). Kana can be processed by both routes, whereas kanji are processed exclusively by the orthographic route.

Both the posterior superior temporal gyrus (P) and the posterior inferior temporal cortex (O) have a role as the interface to semantics (S). The posterior superior temporal gyrus and the posterior inferior temporal cortex have direct reciprocal connections or indirect interconnections via semantics.

It is possible that kanji are recognized and understood along the orthographic-to-semantic route ( $V \rightarrow O \rightarrow S$  in Figure 2(b)) without reference to its pronunciation ( $O \rightarrow P$  route). As a result, despite having difficulty recalling the *on*-reading, the patient achieved a full score in reading comprehension of mixed kanji and kana sentences in the WAB test.

According to this model, the patient's *on*-reading alexia is explained by damage to the connection from the orthographic to the phonological lexicon ( $O \rightarrow P$  in Figure 2(b)). Her lexical decision in the TLPA was within the normal range. Moreover, *kun*-reading was possible even for those words that could not be read with *on*-reading. These facts indicate that the orthography of words was preserved. In addition, the phonological lexicon was intact because auditory comprehension was normal. Thus, it is conceivable that access from the visual word form to the corresponding phonetic value was interrupted.

On the other hand, the fact that *kun*-reading and specific-reading were relatively preserved can be explained by bypassing the orthography-to-phonology route through semantics. That is, access to the *kun*-reading becomes possible when the orthography of a word connects with semantics, and then the semantic lexical information connects with the phonological lexical information ( $O \rightarrow S \rightarrow P$  in Figure 2(b)).

### Anatomical substrate of on-reading impairment

The lesion was in the posterior middle temporal gyrus. Damage to this area is known to cause agraphia for kanji (Y. Sakurai, Mimura et al., 2008) or lexical agraphia (Ullrich & Roeltgen, 2011) in Western countries. The reason that *on*-reading alexia accompanied agraphia was that the lesion extended over the posterior half of the middle temporal gyrus, which may have extensively interrupted U-fiber connections from the inferior temporal gyrus to the middle and superior temporal gyri.

Alexia with agraphia for kanji and anomia was reported following hemorrhage in the left middle third of the middle temporal gyrus (Yamawaki et al., 2005). The patient did not recall the reading of kanji words, although he could understand the meaning. The study did not report whether *on*-reading or *kun*-reading was more impaired. Taking account of the fact that the lesion was situated more anteriorly in the middle temporal gyrus, and thus that semantic memory was more involved, both *on*-reading and *kun*-reading may have been impaired to the same degree, or *kun*-reading and specific-reading may have been more impaired.

Our patient showed that *on*-reading was selectively impaired whereas *kun*-reading was relatively preserved. Altogether with the aforementioned case, this suggests that the phonetic value of *on*- and *kun*-reading is differently represented in the phonological lexicon site; phonetic information of *on*-reading is located more posteriorly and that of *kun*-reading is located more anteriorly in the superior temporal gyrus.

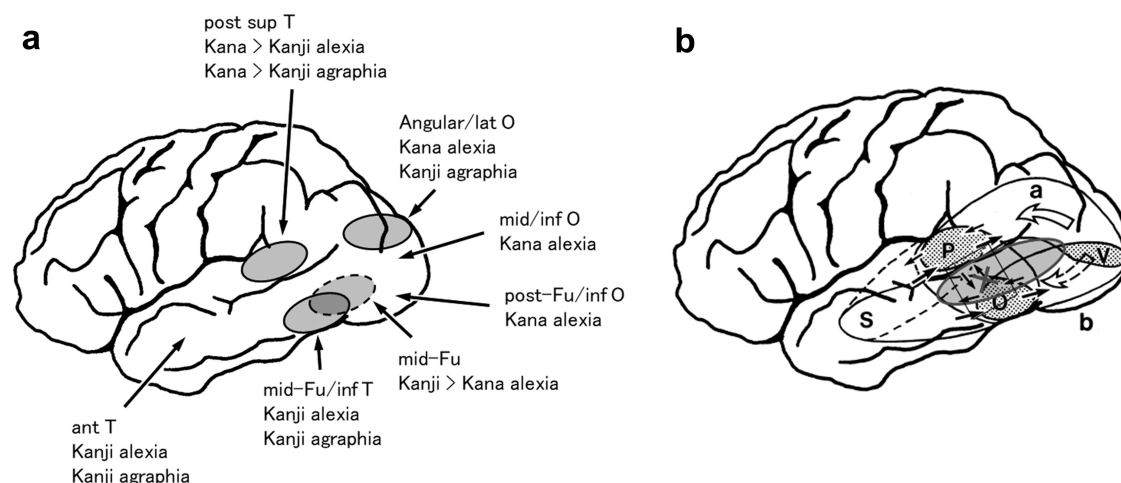
### Lexical agraphia for kanji

Agraphia was due to a character recall deficit. The mechanism is the same as agraphia due to a middle temporal gyrus lesion (Y. Sakurai, Mimura et al., 2008). We think that access from the phonological lexicon to the orthographic lexicon ( $P \rightarrow O$  in Figure 2(b)) was interrupted or the output of visual word form images from the orthographic lexicon was disrupted.

### Extension to European languages

In summary, the patient showed alexia with agraphia for kanji characterized by *on*-reading alexia and lexical agraphia. The lesion was in the white matter under the posterior half of the middle temporal gyrus and interrupted fiber connections between the posterior superior temporal gyrus (the site of the phonological lexicon) and the posterior inferior temporal gyrus (the site of the orthographic lexicon), resulting in *on*-reading alexia and lexical agraphia. In contrast, *kun*-reading and Jukujikun-reading may have bypassed the orthography-to-phonology route through semantics (orthography-to-semantics, and then semantics-to-phonology).

The *on*-*kun* dissociation supports the view that there are two distinct pathways from the orthographic to the phonological lexicon: the direct pathway and the indirect pathway via semantics (Beeson & Rapcsak, 2010). The present study and our previous study (Y. Sakurai et al., 2006a) demonstrate that the two pathways are dissociable. *On*-reading depends on the direct pathway, whereas *kun*-reading, which is more associated with semantics, depends on the indirect pathway. If the direct pathway is not



**Figure 2.** Lesion localization of kanji alexia and kana alexia and the anatomically constrained dual-route reading model. (a) Neural substrates of the postrolandic alexia with regard to kanji and kana. Data are derived from our previous studies (Y. Sakurai et al., 2010, 2000b; Y. Sakurai, Terao et al., 2008; Y. Sakurai et al., 2006a, 2006b) and that of another researcher (Sasanuma, 1975). Kana > Kanji: Kana are more prominent than kanji, post sup T: posterior superior temporal gyrus, lat O: lateral occipital gyri, mid/inf O: middle and inferior occipital gyri, post-Fu/inf O: posterior fusiform and inferior occipital gyri, mid-Fu/inf T: mid-fusiform and inferior temporal cortex, post inf T: posterior inferior temporal cortex, ant T: anterior temporal lobe. (b) Dural-route model of reading. In the phonological route (a), which performs successive grapheme–phoneme conversion, visual information of words and letters goes from the primary visual cortex (V) to the posterior superior temporal gyrus (Wernicke’s area), where the phonological lexicon of words (P) exists, via the lateral occipital gyri and the deep perisylvian temporoparietal cortex. In the orthographic route (b), which performs holistic whole-word recognition, visual information of words and letters goes from the primary visual cortex to the posterior inferior temporal cortex (the so-called visual word form area), where the orthographic lexicon of words (O) exists, via the fusiform gyrus. Kana can be processed by both the orthographic and the phonological routes, whereas kanji are processed exclusively by the orthographic route. Both the posterior superior temporal gyrus and the posterior inferior temporal cortex have a role as the interface to semantics (S). The posterior superior temporal gyrus (P) and the posterior inferior temporal cortex (O) have direct reciprocal connections or indirect interconnections via semantics (S). The patient’s lesion is shown by a gray ellipse, and damaged fiber connections for *on*-reading alexia are denoted using “X.” Revised with permission from Sakurai (2004). a: Phonological pathway, b: orthographic pathway, O: orthographic lexicon, P: phonological lexicon, S: semantic storage site, V: primary visual cortex.

available, only the indirect pathway will be used, making *kun*-reading possible, as in the present patient. In contrast, if semantic storage in the indirect route is damaged, only the direct pathway will be used, enabling *on*-reading without understanding, as in patients with Japanese semantic dementia.

This *on*–*kun* dissociation is clinically important because it provides a strategy for rehabilitation of *on*-reading impairment: semantic association or semantic lexical help by the bypassing (indirect) route may serve to compensate for the impairment. The same phenomenon, if it occurs in European languages, would appear as a symptom in which pronunciation of regular words is recalled more poorly than that of irregular or exceptional words that are directly associated with semantics.

Similar symptoms may also occur in patients with developmental dyslexia with abnormal gyrification in the left superior temporal sulcus and middle temporal gyrus (Caverzasi et al., 2018) or changes in white matter in the left temporoparietal region (Peterson & Pennington, 2015). In either case, the semantic association strategy will facilitate the learning of words.

Further study is needed to determine whether the same lesion produces impairment of pronunciation recall in European languages.

## Disclosure statement

The authors report no conflicts of interest.

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