Conversion of semantic information into phonological representation: a function in left posterior basal temporal area

Keiko Usui,1 Akio Ikeda,2 Motohiro Takayama,1,3 Masao Matsuhashi,1 Jun-Ichi Yamamoto,1 Takeshi Satoh,1,3 Tahamina Begum,1 Nobuhiro Mikuni,3 Jun B. Takahashi,3 Susumu Miyamoto,3 Nobuo Hashimoto3 and Hiroshi Shibasaki1,2

1Human Brain Research Center, Departments of 2Neurology and 3Neurosurgery, Kyoto University School of Medicine, Shogoin, Sakyo-ku, Kyoto, Japan

Correspondence to: Hiroshi Shibasaki, MD, PhD, Department of Neurology, Kyoto University School of Medicine, Shogoin, Sakyo-ku, Kyoto, 606-8507, Japan
E-mail: shib@kuhp.kyoto-u.ac.jp

Summary
A unique feature of Japanese language is that its written sentences consist of both morphograms (kanji) and syllabograms (kana). Despite extensive research by PET, functional MRI and magnetoencephalography, the issues of the difference (or the similarities) between the processing of kanji and kana, and between word reading and object/picture naming have not been resolved as yet. This study investigated the function of the posterior basal temporal area in the language dominant hemisphere in auditory and visual language processing, with special emphasis on semantic and phonological recognition. Subdural electrode grids were placed on the left temporal area of a right-handed woman with intractable temporal lobe epilepsy as part of a pre-surgical evaluation. Her dominant hemisphere for language was shown to be the left on the Wada test. Electric stimulation of 50 Hz was applied to the electrodes during the tasks related to language. Our results showed a clear distinction in the responses and/or performance of the subject depending on the type of characters presented and the tasks employed. Electric stimulation of a localized area in the posterior basal temporal lobe caused neither comprehensive nor productive deficit in the tasks using auditory stimuli. In the tasks using visual stimuli, in contrast, impairments were observed in (i) reading of kanji words and (ii) naming of objects/pictures and geometric designs, but not in (iii) reading of kana, (iv) copying of kanji, kana and geometric designs, and (v) using tools. The subject maintained full comprehension of spoken language, suggesting that the auditory tasks are not processed in the posterior basal temporal area. The fact that the impairment of kanji reading and disturbance of object/picture naming were elicited by electric stimulation of the same area indicates that there is at least one anatomical area that is used commonly for kanji (but not kana) and object processing. The conceptual entity of the test items supposedly was recognized correctly, but the concept failed to be matched to correct phonological representation. The left posterior basal temporal area, therefore, has an important function of connecting visual semantic information into phonological representation.

Keywords: left posterior basal temporal area; kanji versus kana reading; recognition of morphogram/syllabogram; picture naming; electric cortical stimulation

Abbreviations: BTLA = basal temporal language area; fMRI = functional MRI; MEG = magnetoencephalography; TLE = temporal lobe epilepsy

Introduction
The existence of a basal temporal language area (BTLA) was first demonstrated by electric cortical stimulation in patients with temporal lobe epilepsy (TLE) (Lüders et al., 1986). The area was considered to be in the fusiform gyrus of the language dominant hemisphere because the application of electric stimuli to that area at high intensity caused a transient global aphasia, in terms of both comprehensive and expressive language functions, without disturbance of visual memory or constructional apraxia. Electric stimulation at lower intensity, on the other hand, induced just anoma...
Table 1 Cognitive performance before and 1 month after surgical treatment

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<td>Delayed reproduction</td>
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WAIS-R = Wechsler Adult Intelligence Scale-Revised, Japanese version; WMS-R = Wechsler Memory Scale-Revised, Japanese version; WAB = the Western Aphasia Battery, Japanese version; AQ = aphasia quotient; CQ = cortex quotient.

There have been conflicting reports concerning the processing of the two different sets of orthographic representations in Japanese, i.e. kanji (morphograms) and kana (syllabograms). Features of kanji and kana were described in detail elsewhere (Iwata, 1984). Briefly, kanji characters are visual figures strongly associated with semantics, and thus their pronunciations depend on the context in which they appear. Kana letters are phonological entities somewhat comparable with the alphabet in European languages. Some investigators have claimed that kanji and kana are processed in two separate pathways (Iwata, 1984; Sakurai et al., 2000a), while others assumed that there was no specific pathway for processing kanji (Sugishita et al., 1992). Studies on brain function in normal subjects also reported contradictory data. Functional neuroimaging studies using PET or functional MRI (fMRI) demonstrated that the fusiform gyrus was activated in language tasks of kanji, whereas kana activated different areas (Tokunaga et al., 1999; Nakamura et al., 2000; Sakurai et al., 2000b). Another study using magnetoencephalography (MEG), however, reported that there was no difference between kanji and kana processing (Koyama et al., 1998).

Another feature of the BTLA is that this area is involved in picture naming. A recent activation study in normal subjects reported that the left fusiform/inferior temporal-occipital gyri were activated during picture naming (Murtha et al., 1999). Their finding may be closely related to kanji processing, because the object/picture and the kanji character have a common property in terms of semantic concept. Namely, for example, a kanji character 机 (tsu-ku-e, desk) is strongly associated with an image of the furniture that is used for reading or writing without involving phonology.

Although lesion studies, neuroimaging, MEG and transcranial magnetic stimulation (TMS) data provide important insight into regional brain functions, they do not clarify the direct relationship between the phenomena and their underlying mechanism. In contrast, as currently done in epilepsy surgery, extraoperative electric stimulation of the cortex by means of chronically implanted subdural electrodes is suitable for the study of language processing by creating a transient reversible impairment precisely in the target area of the cortex. Despite its great potential, stimulation has rarely been applied to the study of BTLA in subjects whose primary written language involves the use of kanji (morphograms) and kana (syllabograms). This is the first study to investigate, by using direct electric stimulation, the BTLA in association with kanji processing compared with other language functions such as object/picture naming. After describing the experimental procedures, we present distinctive results regarding the response and performance of the subject, which strongly depend on the type of stimuli (auditory/visual) and the tasks (reading/copying). We then discuss in detail the mechanism of the dissociation of functions we found in kanji/kana reading and object/picture naming in particular.

**Methods**

**Patient**

A 24-year-old right-handed woman with intractable mesial temporal lobe epilepsy (MTLE) was evaluated for surgical treatment. She had suffered from epileptic seizures since the age of 10 years. Her seizures were complex partial seizures preceded by abdominal aura which occurred three times per week even when on appropriate medication. Neurological examination was unremarkable, and her cognitive and language functions were found to be normal on neuropsychological batteries (Table 1). Extensive evaluation including prolonged scalp EEG and video monitoring, MEG, MRI and...
[\textsuperscript{18}F]fluorodeoxyglucose-PET (FDG-PET) was performed. Scalp-recorded ictal and interictal epileptiform discharges were located in the left parieto-occipital region. The MEG data suggested equivalent current dipoles for the interictal epileptiform discharges in the left parietal lobe. Brain MRI, however, disclosed a T\textsubscript{2}-weighted high signal intensity lesion associated with calcification in the left medial to basal temporal area (Fig. 1). In that area, regional glucose metabolism was decreased on FDG-PET. The Wada test showed that her language dominant hemisphere was on the left. Accordingly, the patient underwent a craniotomy to implant subdural electrode grids to locate the epileptogenic zone as well as functional areas. This invasive procedure was approved by the Ethical Committee of Kyoto University Graduate School of Medicine (No. 79) and written informed consent was obtained from the patient. After 2 weeks of investigation, the tumour and the epileptogenic zone thus identified were surgically resected and the patient became seizure free. Postoperative neuropsychological examination showed no significant cognitive deficits (Table 1).

**Procedures**

Three sheets of subdural electrode grids were placed on the left hemisphere: one with 20 (4 \times 5) electrodes on the parietal lobe (plate III in Fig. 2D), another with the same electrode arrangement covering the posterior region of the lateral and inferior temporal lobe (plate I) and another grid with 16 (8 \times 2) electrodes on the anterior aspect of the latter (plate II). Electrodes were made of platinum and embedded in a silastic sheet with a centre-to-centre interelectrode distance of 10 mm. The disc of each electrode was 4.0 mm in diameter with an exposed surface area of 2.3 mm. Skull radiographs and MRI with the electrodes in place were taken for reference to register co-planar pre-surgical MRI (Fig. 2).

Ninety-six hours after subdural electrode implantation, sessions for functional brain mapping started. Details about the methods of electric stimulation have been described elsewhere (Ikeda et al., 1992). Electric current in square waves of alternating polarity each with a duration of 0.3 ms was delivered to a pair of subdural electrodes at a frequency of 50 Hz for 1 s, and the current was increased by 1 mA increments to a maximum of 15 mA. The duration of electric stimulation was then increased by 1-s increments until the maximum of 5 s. Whenever afterdischarges were induced, the test was repeated with the same or lower current. At the maximal current, each pair of electrodes were first screened for positive or negative motor responses. Language functions were then examined using paragraph reading.

On screening for language function, two pairs of electrodes situated adjacent to each other on the BTLA (I-12/17 and I-13/18) induced reading impairment upon bipolar stimulation without any positive or negative motor responses. In order to localize the language area more precisely and to specify the nature of language function in that area, ‘referential’ stimulation was applied with a common indifferent electrode used as a reference. Namely, an electrode on which neither positive nor negative motor responses nor reading impairment were induced with no afterdischarges during screening was chosen as the reference electrode (II-16). Among the two pairs of electrodes, one (I-18) did not show any language impairment on the referential stimulation and thus was excluded from further investigation. Of the remaining three electrodes, two (I-12, I-13) that were important in deciding the area of surgical treatment were investigated for further language function as follows.

Initially, the patient’s consciousness and speech comprehension were examined by simple verbal commands such as ‘touch your nose with your right hand’. Then the tests using visual stimuli were done systematically (Fig. 3). Word reading was tested in both kanji and kana. Each test item was printed on a card and presented in the central visual field. For kanji word reading, one-character words and two-character words were used. All of them were concrete
words in common use and of high familiarity. In kana reading, the same words as used for kanji tasks were used. They consisted of three or four kana letters. In addition to the former two sets of word reading tests, reading tests of three-letter kana non-words were also performed. Object/picture naming was then tested using concrete objects (tools), line

Fig. 2 Placement of subdural electrodes shown in the coronal (A) and lateral (B) X-rays, T1-weighted axial MRI (C) and diagram (D). Electrodes I-12 and I-13 (black circles in D and white circles in C) induced alexia for kanji during electric stimulation.

Fig. 3 Examples of visual stimuli used in the present study; kana words, kana non-words, one-character kanji words, two-character kanji words, pictures and geometric designs.
drawings of concrete objects and geometric planar designs. All materials were those commonly seen and used in daily life. Each task consisted of 10–18 items, depending on the tasks, and the electric stimulation was given when the patient finished the first two items. All the tasks were first performed without stimulation and then repeated during stimulation. Finally, the patient’s recognition of the presented visual stimuli was tested by making her copy words, non-words and geometric designs, and by making her actually handle the tools. All sessions were videotaped, and EEG were recorded simultaneously.

**Results**

**Responses in verbal and visual tasks**

Table 2 summarizes the rate of correct responses in a variety of tasks with and without electric stimulation. Without electric stimulation, all tasks were performed correctly. Under the influence of electric stimulation, the performance strongly depended on the type of tasks. In the verbal command task, she responded promptly and correctly to spoken orders. This indicates that the patient was alert and her comprehension of spoken language was intact during electric stimulation. Some of the tasks with visual items, however, were impaired by stimulation. All tasks related to kana were performed without mistakes. In contrast, reading of kanji words and naming of concrete objects, pictures and geometric designs were impaired. A distinctive feature in the present case was that the patient copied kanji words and geometric designs correctly and used tools without any mistakes, even though she could not read the kanji words or name objects/pictures and geometric designs. When the patient copied kanji words or geometric designs, she looked at them just for a short period of time, and started writing and/or drawing without looking at them again. Her motions did not indicate that she was copying them bit by bit.

**Kanji reading**

Reading of kanji words was completely interrupted during electric stimulation. The patient made two clearly different types of errors; 84% of errors were interruption of reading, and the remaining 16% were categorized as semantic paraphasia. In the latter type of errors, for example, a visual test item of kanji word 水 (pronounced as ‘mi-zu’, meaning water) was pronounced mistakenly as ‘ta-ni’ (written as 谷, which means a valley). In another session, a test item 松 (pronounced as ‘ma-tsu’, meaning a pine tree) was pronounced mistakenly as ‘ta-ke’ (written as 竹, meaning bamboo).

Even though she was alexic, she wrote kanji words correctly without interruption upon visual presentation. This indicates that her visual perception and recognition of the configuration of kanji characters were intact. When kanji words and kana words were presented alternately, only kanji reading was hindered. This suggested that selective alexia for kanji was induced during the electric stimulation.

**Naming of objects, line drawings and geometric designs**

As also shown in Table 2, naming of objects/pictures was disturbed during electric stimulation. In almost the same way as for kanji reading, the patient made two categorically different types of errors; interruption and paraphasia. When naming was impaired, interruption of naming occurred in 70% of cases. The remaining 30% were paraphasia, or perseverative paraphasia in precise categorization.
Despite complete disruption of naming, the patient still could use the presented objects correctly. This finding indicates that the recognition of structural and functional features of tools was preserved. Immediately after the stimulation, she remembered the object or picture that she could not name correctly. Naming of geometric designs was also disturbed, but copying of them was possible. After the stimulation, the patient reported that she knew the shape of the design very well, but its name did not come out.

Discussion
The primary interest of our study was on the detailed processing of kanji and kana, two Japanese writing systems, and the correlation between processing of words and naming of objects/pictures. By adopting electric cortical stimulation as a direct method to investigate the brain functions, we successfully addressed the dissociation of functions in terms of such issues as response to the tasks with auditory and visual stimuli, and semantic and phonological recognition in relation to the function of the posterior basal temporal area of the language dominant hemisphere.

Auditory versus visual tasks in kanji and kana reading
In this study, we found that electric stimulation of the posterior basal temporal area caused neither comprehensive nor productive deficit in the tasks using auditory stimuli. With visual stimuli, however, impairments were observed, depending on the type of characters presented and the tasks allotted. The subject maintained full comprehension of spoken language, suggesting that the auditory tasks are not processed in the posterior basal temporal area. In contrast, the visual tasks are processed, at least in part, in this particular area of the brain. Another feature is that reading kanji was disturbed while reading kana was not impaired at all. We also found that copying was intact for both kanji and kana. Thus reading was impaired only for kanji, while visual recognition of words itself was intact for both kanji and kana.

Figure 4 schematically illustrates how auditory and visual tasks are processed and how these are disturbed by electric stimulation of the left posterior basal temporal area. As for the tasks dealing with letters/characters, only kanji reading was impaired, while other tasks were totally intact even with electric stimulation. Although both auditory and visual tasks employed here are language related, the present results suggest that the two tasks are processed in a non-identical manner in the language dominant hemisphere.

Pathways for morphograms and syllabograms in reading kanji and kana
With regard to the cause of alexia for kanji, we speculate that the erroneous responses were induced partly due to a strong association among certain groups of words particularly in Japanese culture. One such group is 岩 (pronounced ya-ma, mountain), 谷 (ta-ni, valley), 河 (ka-wa, river) and 水 (mi-zu, water); and another group is 松 (ma-tsu, pine tree), 竹 (ta-ke, bamboo) and 梅 (u-me, plum tree). The semantic paraphasia observed in this study is by itself evidence that words in kanji are processed in this particular cortical area.
The difference observed in the visual tasks dealing with kanji and kana under electric stimulation provides a significant insight into the processing of morphograms and syllabograms. Sentences in Japanese usually consist of both kanji and kana words. We carefully chose the words used in our test not to be influenced by the preference and/or the intellectual level of subjects. The result, therefore, is not a matter of complexity in terms of difficulty in reading. The fact that only kanji reading was impaired and not kana suggests that these two sets of characters are processed in a non-identical manner in the brain.

In Japanese orthography, each kana letter has a single phonological value but does not evoke semantic connotations. Kanji characters, on the contrary, are associated with semantic entities and their pronunciation usually depends on the context. Considering these characteristic differences between kanji and kana, it is highly likely that the selective impairment of kanji reading is caused by the difference in functional representation of kanji and kana.

Although extensive research has been carried out by indirect methods such as PET, fMRI and MEG, the issue of whether there is a distinction between the process of kanji and kana has not been resolved so far. Our finding that reading of phonetic entities (kana) is intact while reading of semantic ones (kanji) is impaired under electric stimulation of the BTLA clearly shows that morphograms and syllabograms are processed in different pathways. Furthermore, as shown in Fig. 4, copying was not impaired for either kanji or kana, suggesting that the difference observed is not caused simply by what the subject saw, but by how her brain processed what was seen depending on the type of task. When the task is reading, the brain automatically processes words based on morphogram/syllabogram dichotomy. When the task is copying, on the other hand, the brain automatically processes words in a pathway different from semantic/phonetic processing. Our study using electric stimulation as a direct method provides clear evidence that, in Japanese, the semantic and the phonetic aspect of kanji are processed in different pathways, not identical to each other.

A dual coding hypothesis (Bookheimer et al., 1995) claimed that there are two pathways for word reading; in an indirect route, a word is decomposed into orthographic units and sequentially transcribed into their corresponding sounds, while in a direct pathway a word as a whole is associated directly with its semantic or articulatory representation. It is assumed that words in European languages would be processed in the direct pathway during silent reading. During reading aloud, in contrast, words are processed in the indirect pathway because they are recognized as phonological entities. A study of English language processing using PET further suggested that the direct pathway involved the inferior temporal area (ventral pathway) and the indirect pathway ran through the superior temporal to inferior parietal region (dorsal pathway) (Bookheimer et al., 1995).

Despite a distinctive difference in the system seen in Japanese and European languages, the processes as morphograms and syllabograms show similarities. Since the electrodes in our study covered the inferior temporal area, it is postulated that kanji is processed in the ventral pathway. Although the dorsal pathway was not studied here, kana may be processed in the dorsal pathway because both the alphabet and kana represent sound.

Similarities of word reading to object/picture naming

The issue of whether the process of word reading and that of object naming are different or partially similar has long been debated (Caramazza, 1996). It has been widely found that the posterior inferior temporal region is activated in language and/or object processing (Cabeza et al., 2000 and references therein). Other studies using electric stimulation of the human cortex (Hart et al., 1998), event-related cortical potentials (Nobre et al., 1994) and repetitive TMS (Stewart et al., 2001) also associated this region with word reading or object naming. Functional roles allocated to this area, however, were variable: object recognition (Stewart et al., 2001; Whatmough et al., 2002), face processing (Puce et al., 1996), pre-lexical processing of words (Nobre et al., 1994), semantic processing (Vandenbergh et al., 1996; Hart et al., 1998; Murtha et al., 1999) and phonological retrieval (Price et al., 1997). Another study using PET associated this region not with a distinct but with an intermediary role in lexical retrieval (Damasio et al., 1996). A recent study using PET proposed that the left fusiform gyrus carries three separate language functions which are attributed to three distinct anatomical subregions, the most posterior part of the left fusiform gyrus being involved in object recognition, the most anterior part in semantic processing and the intermediate portion in phonological retrieval (Moore et al., 1999).

Considering these conflicting reports and vague understanding of the functions of each area in the brain, we tried to identify the area for the process of word reading and object naming, and the actual function of processing in detail. It was found that the impairment of kanji reading and disturbance of object/picture naming were elicited by electric stimulation of the same area, indicating that, in the sequence of processing, there is at least one anatomical area that is commonly used for kanji (but not kana) and object processing. The implication is that two distinctly different functions, i.e. one dealing with words and the other dealing with objects, are carried out by involving the same area in the brain.

Semantic information and phonological representation

As discussed in the previous sections and shown in Fig. 4, two sets of characters in the Japanese language, kanji and kana, are processed in a non-identical manner; tasks involving kana are intact for both reading and copying; reading is impaired while copying is intact in the tasks involving kanji. Although
kanji and kana are both language writing systems, signal processing in the brain is not the same for them. The present experiments also showed that in the tasks involving objects and/or pictures, naming was impaired while using was intact. The striking similarities between the responses in the tasks dealing with kanji and objects/pictures are shown in Fig. 4. Reading and naming were disturbed while copying and using were intact during electric stimulation of a restricted area of the posterior basal temporal area in the left hemisphere which was proven to be language dominant by the Wada test.

The fact that the oral response was disturbed whereas copying and using were intact indicates that the semantic part of visual information can be processed without any disturbance. Since the patient copied both kanji words and simple geometric designs just by looking at them for a very short period of time and without looking at them again during her writing and/or drawing, it is highly likely that she understood the objects instantaneously regardless of their representing sounds and/or names. The conceptual entity of the test items in both reading/naming and copying sessions, therefore, was supposedly recognized correctly, but the concept failed to be matched to correct phonological representation.

With regard to the type of errors which the patient made in reading kanji and in picture naming under electric stimulation, the majority in both sessions were total interruption of reading or naming; 84% in kanji reading and 70% in picture naming. The remaining portion was paraphasia; 16% in the case of kanji reading and 30% in picture naming. A minor difference we observed was that paraphasia in kanji reading was semantic, whereas it was perseverative in picture naming. As discussed in the previous sections, some words in Japanese have a strong conceptual and/or cultural association among certain groups. Therefore, when the patient conceptually understood a kanji word while failing to match it with the correct phonological representation, it is highly likely that a false representing sound comes from one of the words in such a group instead of the sound of a word totally unrelated to the correct one. A good example is the session in which a test item は (pronounced as ‘ma-tsu’, meaning a pine tree) was mistakenly called as ‘ta-ke’ (written as け, meaning bamboo) under electric stimulation. Both are familiar and typical in the picturesque scenery of the countryside or in traditional Japanese gardens.

In the case of picture naming, on the other hand, such a strong cultural and conceptual connection rarely exists among the pictures used in our experiments. When the patient conceptually understood a picture while failing to match it with its correct phonological representation, therefore, a false representing sound tends to come not from a specific group of words but from something very close to the situation the patient was in, i.e. what she saw a moment before. As a result, the patient repeated the same word for the next picture.

Although the two separate terms are used for paraphasia observed in kanji reading and picture naming in this study, both involve the conceptual understanding (or semantic information in a broad sense) of what the patient sees and their representing sounds. It can safely be assumed, therefore, that the process and mechanism involved here for errors in kanji reading and picture naming are identical, and the only difference is the origin of a false representing sound, i.e. a culturally connected group of words in the case of kanji reading versus the name of object which was presented just before in the case of picture naming.

Based on the fact that both kanji reading and picture naming were impaired by electric stimulation in almost the same way, the study provides a clear understanding of how these two distinctly different functions, reading words and naming objects, are processed in a similar manner in the brain. The results here strongly indicate that one of the functions of the left posterior basal temporal area is the conversion of visual stimuli carrying semantic information into their phonological representations.

Possibilities for further study
Since relatively little has been reported with direct experimental evidence before our study, selective deficits are still one of the significant issues to be settled. Hart et al. (1992) showed the existence of language-based and visually based representational systems, which explains the category-specific deficits they observed in a patient with cerebral damage. They also indicated the processing subsystems within language. Their findings provide a relevant example of evidence that the dissociation of language function is not specific for BTLA, but is observed in other dimensions of brain functions.

Some studies have suggested that the left TLE might be associated with intra- and interhemispheric reorganization of language functions (Saykin et al., 1995; Springer et al., 1999; Billingsley et al., 2001). Although the present patient had a tumour in the left basal temporal area, she showed no language deficits either before or after tumour resection, implying that her dominant hemisphere for language remained on the left without reorganization of functional areas, as proved by the Wada test, and her language processing is functionally normal. Therefore, although this is a study of a single case, the distinctive and clear findings in our patient may also be applicable to normal subjects. Our study using direct electric stimulation significantly improves the understanding of what is strongly related to multiplicity of domains and/or systems involved in the processing architecture in the brain.

Although the study of a whole brain is beyond the scope of subdural recording, analysis of processing in the area comparable with the BTLA in the non-language dominant hemisphere will provide us with further knowledge regarding language and object processing. We also plan to study discharges occurring remote from the stimulation site (Ishitobi et al., 2000). In addition, the study of picture naming employing items in different categories, such as animate and non-animate objects, and faces, will give
important insight into storage sites of names and the naming process itself.

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