Memory Process for Phonologically Ambiguous Graphemes in the Second and Native Language: An fMRI Study Using Japanese Speakers

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Introduction
Neuroimaging studies in a clinical or educational domain (i.e. developmental dyslexia, illiteracy and the second language acquisition) have been increasing [1,2,3,4]. Previous study [5] reported that Japanese speakers exhibited unique brain activities for memorizing phonologically ambiguous graphemes (e.g. "r"-/r/ and "l"-/l/) compared with non-ambiguous ones. The cognitive difficulty in the r/l graphemes for Japanese speakers seems to be analogues to that of developmental dyslexia or illiteracy. Both find harder to associate graphemes with relevant phonemes as the grapheme-to-phoneme correspondence is not clear for them. However, neural activities for the second language (L2) might differ from the native (L1) ones. In the r/l ambiguity for Japanese speakers, phonological distinction between /r/ and /l/ itself is incomplete, contrasting to the native clinical case in which the only grapheme-to-phoneme association is not well fixed. The purpose of the present study was to examine the neural basis underlying the memory process for phonologically ambiguous graphemes in L2 and L1 using fMRI. We investigated the issue applying working memory tasks for r/l and *kana* syllables in Japanese speakers. Some Japanese syllables hold irregular, one-to-many, correspondence with *kana* scripts. We utilized these exceptional *kana* scripts as the L1 ambiguous graphemes for equivalents of the L2 ambiguous graphemes (i.e. "r" and "l").

Method
Subjects Ten right-handed native Japanese speakers (F/M=6/4, age 21-43) who gave written informed consent participated in the experiment. They had taken no special training for English skills after completing a conventional English curriculum in their higher education.
Tasks Syllable working memory task [5] was conducted using either English letters or and *kana* scripts. Both types of task had the same format (Figure 1). First, three target syllables were visually presented one at a time. After 1.5 second, a probe stimulus appeared requesting subjects to decide whether the probe was present in the targets. Responses were collected through the left hand button. A task block contained 5 trials and each task sequence consisted of 4 task blocks. Rest periods, in which an asterisk mark ('*') was presented, were interleaved with the task blocks. As probe stimuli, *katakana* scripts were used for *kana* task sequences, while capital letters for the English syllable task sequences.
Experiment Design The experiment consisted of two ambiguous syllable task sequences and two non-ambiguous ones. In the ambiguous *kana* task (AK) and l/r task (RL) sequence, graphemes-to-phoneme correspondence was one-to-many for Japanese speakers. For the comparison, the normal kana task (NK) and the b/n task (BN) sequence were included in which all stimuli had one-to-one grapheme-to-phoneme correspondence.
Data Analysis A gradient recalled echo EPI sequence was employed for functional studies on 3T MR scanner (GE, Signa VH/i 3.0T). The imaging parameters were TR 3000 msec, TE 30 msec, FA 90 degree, FOV 22 cm, and slice thickness 3mm plus 1mm gap. Thirty axial slices were obtained. The fMRI data were analyzed using SPM99 (Wellcome Department of Cognitive Neurology, London, UK). A random effect model was applied with the height threshold $p=0.005$ at voxel level (uncorrected), and extent threshold $p=0.05$ at cluster level. One sample t-test was conducted to examine the task specific activation for each task sequence. Paired t-test was also done to compare activations between the RL and AK sequences.

Results and Discussion
The activation maps for the four task sequences are summarized in the Figure 2. The right middle frontal gyrus (MFG; BA 9) exhibited extensive activation in the RL and AK sequences compared with BN or NK task sequence (Figure 2; pink arrows). The greater activation in the area indicates that the intensive cognitive resource was required for memorizing phonologically ambiguous graphemes either for L1 or L2 syllables. Although extensive activation was detected in the left SMG (BA 40) for both phonologically ambiguous tasks (Figure 2; blue arrows), it was more prominent in the AK sequence. The paired t-test confirmed the superior activation in the left SMG for the AK sequence (Figure 2; yellow arrow). The area is considered to be temporary storage for the phonological information [6], suggesting that subjects tried to memorize ambiguous *kana* scripts as phonological codes, despite inaccessibility to definite phonemes. The result is consisting with the previous study reporting that phonological coding is less involved in verbal working memory tasks for L2 words [7]. In conclusion, the present study clarified that the memory processes for phonologically ambiguous graphemes in L1 and L2 are not mediated by an unitary neural system.
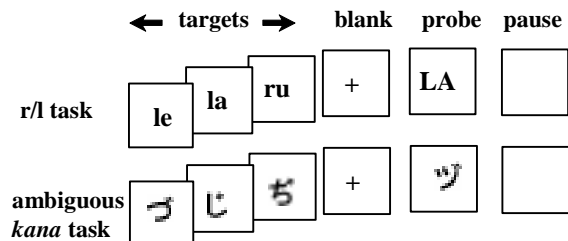

Figure 1

Figure 2

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