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Visual imagery while reading concrete and abstract Japanese kanji words: An fMRI study

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ABSTRACT

Neuroimaging studies have investigated differences in neural correlates between abstract and concrete concepts but this has not been done with Japanese participants. Concrete words have higher imageability than abstract words, such that they elicit more visual imagery. The present study used functional MRI to investigate brain activity of Japanese participants ($N = 16$) during generation of visual images for written concrete or abstract Japanese kanji words. Concrete words elicited significantly more activation than abstract words in the left middle frontal gyrus (LMFG), bilateral superior frontal gyrus, and left fusiform gyrus (LFG). Psychophysiological interaction (PPI) analyses were performed to assess LMFG and LFG functional connections. LMFG activity was accompanied by increased functional interaction with the left superior parietal lobule (LSPL), and LFG activity was accompanied by increased functional interaction with the LMFG. This finding suggests that the LMFG plays an important role in visual imagery, with interactions between this region and both the LSPL and LFG.

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1. Introduction

Imagery elicited by words involves recalling the sensory qualities of objects. The vividness of the imagery is highly correlated with word concreteness. Paivio (1991) proposed a dual-coding theory such that cognition operates via two neural pathways associated with verbal and imagery-based systems. Concrete words are more easily recalled than abstract words due to their greater imageability. Concrete words are acquired through sensory experiences, in contrast to abstract words, which are acquired through their use in sentences and their relationships with other concepts. Abstract words cannot be learned until a certain representational capacity is developed that permits the utilization of linguistic contexts (Bloom, 2000). Typically, concrete words have a processing advantage over abstract words. A deep dyslexic patient with a left hemisphere injury had a specific impairment for reading abstract words but was able to read concrete words, which indicates that different neural pathways are utilized for processing these two stimulus types (Coltheart et al., 1980).

Functional neuroimaging studies have recently investigated neural substrates for understanding language, specifically focusing on differences between concrete and abstract words (D'Esposito et al., 1997; Mellet et al., 1998; Jessen et al., 2000; Wise et al., 2000; Fiebach and Friederici, 2004; Whatmough et al., 2004; Mestres-Missé et al., 2009). In an fMRI study, participants generating visual imagery while listening to concrete words showed more brain activity in the left inferior temporal area (Brodmann's area; BA37) and in the occipital association cortex (BA19), in contrast to a condition where they simply listened to abstract words (D'Esposito et al., 1997). Visual mental imagery appears to be a function of the visual association cortex, with its generation localized to the left side. In a PET study, listening to concrete word definitions associated with mental images specifically elicited activation of the bilateral inferior temporal gyri as compared to abstract words (Mellet et al., 1998). For the latter, greater activation of the bilateral superior temporal gyri and the anterior part of the right middle temporal gyrus was observed compared to concrete words. In another PET study, activity increased with noun imageability in the left mid-fusiform gyrus (Wise et al., 2000). In an fMRI study, participants made lexical decisions about word and pseudo-word stimuli, and the results showed right hemisphere activation during the processing of abstract language representations (Kiehl et al., 1999). A metanalysis combined data from 19 neuroimaging studies to

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identify differences in neural representations of abstract and concrete concepts. The comparison of concrete versus abstract concepts showed significant activation differences for the left fusiform gyrus (LFG), left precuneus, left parahippocampal gyrus, and left posterior cingulate. There were also activation differences for the left inferior frontal gyrus, left middle temporal gyrus, and left superior temporal gyrus. These differences indicate that concrete concepts are relatively easy to image with a corresponding engagement of the perceptual system, while abstract concepts appear to engage the verbal system (Wang et al., 2010).

However, no previous study has required participants to generate visual imagery during both concrete and abstract stimulus conditions. Visual images of concrete stimuli are associated with left inferior temporal gyrus activation; however, no comparisons of visual imagery for concrete and abstract stimuli have been conducted (D'Esposito et al., 1997; Mellet et al., 1998). Previous lexical decision task studies demonstrated a correlation between noun imageability and increasing brain activity in the LFG, although such a judgment-based button pressing task does not explicitly reflect the generation of visual imagery (Kiehl et al., 1999; Wise et al., 2000; Fiebach and Friederici, 2004; Whatmough et al., 2004). To investigate possible brain circuit differences for visual imagery across concrete and abstract representations, we developed a visual imagery task that required participants to generate visual images for both abstract and concrete kanji words.

Most previous studies of visual imagery have used alphabetical letters and words. Japanese kanji words are morphograms. Iwata (1984) proposed that kanji words are processed differently from alphabetical letters, such that kanji are semantic stimuli whereas letters are phonological. Brain activation differences between reading kanji and English words have been examined for native Japanese adults, using fMRI. Reading English showed more activation of the inferior frontal and left angular gyri, due to phonological processing and verbal working memory demands (Buchweitz et al., 2009). Patient with lesions of the lower middle frontal gyrus and adjacent anterior precentral gyrus cannot write kanji due to visual imagery impairments (Sakurai et al., 1997).

We investigated whether visual imagery for kanji stimuli is associated with LFG activation as was found for alphabetical language, and hypothesized that the LMFG might play an important role in such imagery. We expected that the differences of brain activity associated with imagery between concrete and abstract kanji words might reveal regions associated with visual imagery specifically. To examine this, we performed psychophysiological interaction (PPI) analyses to identify the regions connected to the LMFG and LFG.

2. Materials and methods

2.1. Participants

Sixteen right-handed Japanese male adults took part in the study (mean age = 26.1 ± 5.9 years, range: 20–36 years). Only male participants were included to rule out any potential influence of sex differences on the present findings.

None of the participants suffered from psychiatric or neurological disorders or had ever sustained a head injury. On the revised Wechsler Adult Intelligence Scale (WAIS-R), all participants showed full-scale intelligence quotients (FIQs) over 80 (mean FIQ = 110.2 ± 11.7; mean verbal IQ (VIQ) = 115.9 ± 13.3; mean performance IQ (PIQ) = 100.4 ± 11.5).

The study protocol was approved by the two ethics committee of Hiroshima University and Matsuda Hospital. Written informed consent was obtained from each participant. Participants were paid 1500 yen per hour (about $17 per hour).

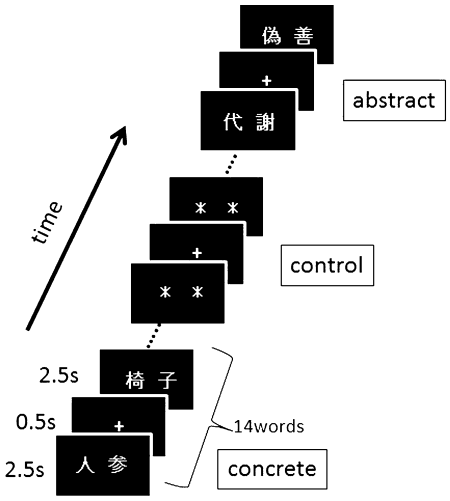

Fig. 1. Stimuli and tasks. Schematic representation of the experimental design. Each word was presented for 2.5 s, with an inter-stimulus interval of 0.5 s. Inter-trial interval (ITI) was 12 s. Concrete, abstract and control blocks were randomly presented five times and each consisted of 14 words, for a total of 70 words.

2.2. Materials

Stimuli consisted of 70 concrete and 70 abstract written kanji words made up of two characters drawn from the Japanese lexicon (Sakuma et al., 2005). The concrete words (e.g., 人参 carrot, 椅子 chair) had high imageability (>5, mean 5.6 ± 0.4) and the abstract words (e.g., 代謝 metabolism, 偽善 hypocrisy) had low imageability (<4, mean 3.4 ± 0.3) on a standardized seven-point scale (Ogawa et al., 1974). Concrete words fell into 14 different categories (word lists by semantic principles, 2004; e.g., tools = 17 words, food = 12, clothing = 10, plants = 8, body parts = 6, materials = 4, dwellings = 4, animals = 2, others = 7). The concrete and abstract words were matched for frequency of occurrence in the Asahi newspaper over 14 years (from 1985 to 1998) ($F(69, 69) = 1.0$, $p = 0.98$) (Amano and Kondo, 2000). The mean number of writing stroke sequences for concrete words was 18.1 ± 5.4, and that for abstract words was 17.8 ± 5.4. This was not a significant difference ($p = 0.72$).

Participants were instructed to read silently and generate visual imagery with their eyes open during blocks of concrete and abstract words. Each block consisted of 14 words of either type, each of which was presented for 2.5 s, followed by a 0.5 s fixation period. Inter-trial intervals (ITI) were 12 s in duration and participants just looked at the fixation cross (Fig. 1). We used control blocks to minimize visual satiation. During the control blocks, participants were instructed only to look at the characters "**", which were repeated 14 times in a block and presented for the same duration as the other stimuli. Each block was randomly presented five times throughout a session. Presentation order of the concrete, abstract and control blocks was counterbalanced across participants. Participants practiced with one block on a personal computer before undergoing the experiment in the fMRI scanner. After the fMRI experiment, the participants were asked "How well could you image the words?" Participants provided ratings for all the words they were shown during the MRI scan, using an imageability rating score ranging from 1 = "Never" to 7 = "Extremely Well".

2.3. fMRI procedure

Structural and functional data were collected using a Symphony 1.5T (Siemens, Munich, Germany). A time course series of 292 scans was acquired using T2*-weighted, gradient echo, echo planar imaging (EPI) sequences. The first six volumes of the fMRI run

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