Gesture in language: How sound symbolic words are processed in the brain

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Abstract

In traditional linguistics, it has been assumed that the sounds of words are not related to their semantic contents, and that meanings of words are not directly linked to sensory systems. Nevertheless, many languages have a word class in which the sound and meaning of words are systematically related. In this study, by using functional magnetic resonance imaging (fMRI), we scanned brain activity in adult Japanese-speakers while they were seeing locomotion videos together with sound symbolic mimetic words, non-sound symbolic adverbs or verbs. Mimetic words were neurally processed differently from non-sound symbolic adverbs and verbs: We identified extensive bi-hemispheric activations in the regions typically associated with nonverbal cognitive processes for mimetic words but not for non-symbolic verbs or adverbs. The results suggest that mimetic words, by their direct sound-meaning link, have dual neural status both as linguistic symbols and non-linguistic iconic symbols that are directly linked to sensory experience.

Keywords: sound symbolism, brain imaging, symbol grounding in language

Introduction

In the tradition of formal linguistics, language is regarded as an encapsulated system which is functionally separated from other cognitive functions. In this tradition, word meanings are assumed to be represented as a set of universal atomic semantic features that are amodal and not connected todirect sensory experiences. Here, sound symbolism, in which the sound and meaning of words are systematically related, is considered to be a marginal phenomenon in language. However, such a statement seems to be too strong when one looks beyond Indo-European languages. Many languages of the world have a large grammatically-defined word class in which sound symbolism is apparent. For example, in Japanese, mimetic words include not only onomatopoeias for animal sounds but also words referring to motion, tactile sensation and emotional states in which sound is not essential. Mimetic words constitute a large open class of words, and new words can be easily created.

These words are frequently used in everyday conversations and newspaper articles, as well as in various forms of verbal arts, from comic books to novels and poems. Japanese is by no means an exception among languages of the world. Many languages of the world have a similar grammatical class of words with clear sound symbolism (Hinton, Nichols, & Ohara,1994; Nuckrolls, 1999; Voetlz & Kilian-Hatz 2001), including most sub-Saharan African languages (Childs,1994) , and many of the South East Asian languages (called Diffloth, 1972; Watson, 2001; Enfield, 2005) and East Asian languages (Lee, 1992; Mok, 2001; Bodomo, 2006). Even in Indo-European languages that do not have a distinct grammatical class for sound symbolic words (e.g., English), linguists (e.g., Bloomfield, 1933/1984; Bolinger, 1950;Firth, 1935/1957) have pointed out that there is clear sound symbolism in some words (e.g., *squeeze*, *squirt*, *squint*, *bump*, *thump*, and *plump in English*).

Starting with Köhler (1929), there has been a body of empirical work, which demonstrates psychological reality of sound symbolism. Köhler found that, when presented with a curvy round shape and a spiky angular shape, one has the intuition that *baluma* is a better name for the former and *takete* is a better name for the latter (see also Ramachandran & Hubbard, 2001; Westbury, 2004). Sapir (1929) also demonstrated that English speakers associate novel words containing the vowel /i/ with smallness more frequently than words containing /a/.

More recently, empirical evidence for the role of sound symbolism in language processing and novel word learning has been accumulated. For example, sound-shape correlates facilitate category learning involving novel objects both in English-speaking children (Maurer, Pathman and Mondloch, 2006) and adults (Kovic, Plunkett, & Westermann, 2009; Nygaard, Cook & Namy, 2009). Imai and colleagues demonstrated that Japanese 25-month-olds and English speaking adults who had no exposure to Japanese could detect the sound symbolism underlying novel mimetic words expressing human locomotion (Imai, Kita, Nagumo & Okada, 2008; Kita, Kantartzis & Imai, in press). They further demonstrated that Japanese- as well as English-reared children were greatly helped by sound symbolism in mimetic verbs when they needed to extend a novel verb.

These effects of sound symbolism are not harmonious with formal theories of linguistics. However, when considered from the neurological perspective (e.g., Maurer & Mondloc, 2005; Ramachandran & Hubbard, 2001), researchers may find sound symbolism much less problematic. However, theneural substrate of the phenomena of sound symbolism is still at a stage of speculation. For example, Ramachandran and Hubbard speculated that sound symbolism involves cross-domain mappings between sound contours and motor patterns in or close to Broca's area (possibly mediated by mirror neurons), and between hand gestures and articulatory gestures in the motor area. Also, if sound symbolism is considered as mimicry of the environment by sound, we might expect the activation in the area responsible for integration between sound and other sensory domains such as vision, motion, and touch (cf. Maurer & Mondoch, 2005) .

There are a few existing studies in the literature that examined neural representation of mimetic words (Hashimoto et al., 2006; Osaka, 2004). For example, Osaka (2004) compared mimetic words expressing pain and nonsense words. He identified the activation of anterior cingulate cortex (ACC) -the region known to be active when people experience pain-- when the pain mimetic words were processed.

Hashimoto et al. (2006) examined the pattern of neural activations when Japanese speakers processed mimetic words for animal sounds (e.g. *wan-wan*, bow-wow) as well as actual animal sounds (dog barking). These researchers showed that Japanese mimetic words for animal sounds (e.g. dog barking) elicited the bilateral activation in the superior temporal sulcus (STS) areas.

Importantly, Thierry et al (2003) demonstrated that there is a functional dissociation between the left and right STS: The left STS is mainly responsible for linguistic sound, whereas the right STS is used when environmental sound is processed. The bilateral STS activation may thus suggest that mimetic words expressing animal sounds have dual nature, being processed both as a linguistic sound (word) and environmental sound. Importantly, in this study, both mimetic words and actual animal sounds were presented auditorily. Hashimoto et al reasoned that mimetic words were processed as environmental sounds because mimetic words sounded like actual animal sound, in connection to Thierry et al.'s results,.and argued that the bilateral activation in the STS area reflected the prosodic property of the mimetic words.

These two studies suggest two important characteristics of mimetic words: (1) they are directly anchored to sensory experiences; (2) mimetic words have dual nature, being processed both as a linguistic sound(word) and environmental sound. However, they leave some important questions concerning the nature of sound symbolism unanswered.

First, it is difficult to determine whether the result by Osaka reflect the sound symbolism in the mimetic words per se, as recent neuro-imaging studies have shown that a word could activate the corresponding sensory area in the brain. For example, several studies revealed that verbs encoding face actions (e.g., *lick*), arm/hand actions (e.g., *pick*), and leg/foot actions (e.g., *kick*) differentially engage their corresponding sensory area in the primary motor and premotor regions (e.g., Hauk et al., 2004; Hauk & Pulvermüller, 2004). Thus, all or most words may be anchored to the sensory experience in some degree, whether or not they carry sound symbolism (Barsalou et al., 2003; Kemeler & Tranel., 2008). Still, it is possible that sound symbolic words, especially mimetic words, are tied to sensory experience more strongly and extensively than non- sound symbolic words due to the iconicity they carry.

Concerning the possibility for the cross-domain mappings between auditory and other sensory modalities in sound symbolic words, it is interesting to see whether or not the bilateral STS activations are also seen for sound symbolic words other than animal sound onomatopoeia. If the sound is strongly tied to the meaning in mimetic words, we might expect to see the bilateral STS activations not only for mimetic words expressing actual sounds but for those representing other sensory domains (e.g. motion) which do not directly involve environmental sound. Furthermore, we might expect to see the same activation pattern even when a mimetic word is presented orthographically instead of auditorily.

To uncover these questions, in this research, we compared the neural representation of mimetic words to that of non-sound symbolic verbs and adverbs, all of which express aspects of human locomotion. We scanned brain activities in Japanese speakers while they were presented with locomotion videos together with sound symbolic mimetic words, non-sound symbolic adverbs or verbs. Here, the words were presented orthographically, and the participants were asked to judge how the word semantically matched the locomotion.

As discussed above, mimetic words are expected to be more strongly tied to perceptual experience than non-sound symbolic verbs and adverbs because of their iconicity in the meaning. In fact, it is possible that mimetic words are processed as "gesture in language" by their sound symbolic nature (Ramachandran & Hubbard, 2001). If so, at a broad level, we may expect activations in the right as well as left hemisphere for the mimetic words, as is the case with non-linguistic gesture (e.g., Kita & Lausberg, 2008). When considering specific regions involved with processing mimetic words for locomotions, if they are in fact tied to sensory experiences more strongly than verbs and adverbs, we might expect stronger activations in the middle temporal (MT), motor, and premotor areas for mimetic words than for verbs and adverbs. Furthermore, if the sound-meaning link is a part of the meaning for mimetic words but not for adverbs or verbs, stronger activation is expected in the STS and superior temporal gyrus (STG) in both hemisphers, as if linguistic sound and environmental sound are both processed (Hashimoto et al., 2006; Thierry et al., 2003).

Method

Participants

Sixteen native Japanese speakers who were either undergraduates or graduates students (mean age =23.7; age range = 22-25; 7 women) participated in the study.

All subjects were right-handed and had normal or corrected-to-normal vision and had no histories of neurological or psychiatric deseases. The data of five participants were excluded from analyses due to artifact components (e.g. head movements) and inadequate performance in the task. The rest of the data from eleven subjects (mean age = 23.4; age range = 22-25; 4women) were used for analyses. All participants gave a written informed consent for participation, and the study was approved by the local ethics committee.

Design and procedure

All participants went through the main experiment (comparing mimetic words, verbs and adverbs) first. After a break, they went through a control experiment, in which the same locomotion videos were presented without words. For the main experiment, we used 16 video clips showing different manners of locomotion, in which an agent moved from left to right on the screen. Each locomotion video was presented together with sound symbolic mimetic words, non-sound symbolic adverbs, or verbs. In half of the trials, the word and the locomotion semantically matched, while in the other half, they did not (e.g., the verb "aruiteiru" (to walk) was shown together with a skipping locomotion). At the end of each block, a fixation point was inserted for 10 seconds to separate the blocks. In each trial, the stimulus (a video clip with a written word) was represented on the screen for 5 seconds. During the stimuli presentation, the participants were instructed to think about the degree of match between the word and the locomotion, but they were asked not to make a response during this period. After the stimuli presentation, the fixation point appeared on the screen for 3 seconds, during which the participants were asked to respond on a scale from 1 to 5 by pressing an appropriate button. There were 4 blocks for each word class and each block consisted of 4 video-word pairs from the same word class. The order of blocks was rotated in the order of mimetic words, verb, and adverb.

All words were shown at the bottom of the video in *hiragana* (a type of orthography each of which represents a syllable). A block design was employed. In each trial, the participants were asked to judge the degree of matching on the scale of 1-5.

In the control experiment, in addition to the videos used for the main experiment, videos showing unnatural biological motions (which were created by morphing videos of natural biological motions) were also shown. The procedure of the control experiment parallels to that of the main experiment except that a word was not presented with the video. During the stimuli presentation, the participants were instructed to think whether the locomotion of the video clip was natural or unnatural as a human movement. After the stimuli presentation, the fixation point appeared on the screen for 3 seconds, during which the participants were asked to respond either 1 (natural) or 2 (unnatural) by pressing the an appropriate key. There were 8 blocks, each of which consisted of 4 video clips. The "natural" trials in which the videos used in the main experiments served as the baseline for visual recognition of the locomotion without verbal description (words).

Stimuli and stimuli validations

Three rating tests were carried out before the fMRI scanning to check whether words representing the three word classes (mimetic words, verbs, adverbs) do not differ in terms of imaginability, familiarity, and age of acquisisition (AOA). All participants were native speakers of Japanese, and none participated in the scanning experiment.

Including the words we used for fMRI scanning task, we prepared 120 words. Twenty-eight participants rated how imaginable each word was. Twenty-seven participants rated how familiar each word was, with a scale from 1 to 7. Finally, we asked other 22 participants to judge around what age they had learned the words to obtain AOA for each word. They were instructed to select the answer from 8 categories; infant period / pre-school age / lower-grade at elementary school/higher-grade at elementary school / junior high school / high school / university or college / do not know the meaning.

The results of the three rating tests indicated that there were significant differences among the three word classes with respect to imaginability (Mimetic words= 5.276 ; Verbs= 6.404 ; Adverbs= 5.616 ;$F(2,81)=3.11$, $p<0.05$) and familiarity (Mimetic words=5.423;Verbs= 6.511 ; Adverbs= 6.08 ; $F(2,78)=3.11$, $p<0.05$). However, importantly, there was no significant difference between mimetic words and adverbs ($t(1,54)=-1.192$ $p=0.119$). Also, the result of Friedman test indicated that there was no significant difference between the mimetic words and the verbs with respect to AOA (Mimetic words=1.523;Verbs=1.545; Adverbs=2.932 ,$p=0.763$), although adverbs were judged to have been acquired later than verbs and mimetic words.

Imaging parameters and analysis

Scanning of fMRI data was performed with a 1.5 Tesla MRI scanner. The fMRI images were obtained using multislice gradient-echo planner imaging (EPI) and were used to produce 20 contiguous, 6-mm thick axial slices covering the whole brain [echo time (TE), 50 ms; repetition time (TR), 2000 ms; flip angle, 90 degree; field of view (FOV), 192 mm; 64 × 64 matrix].

The fMRI data were analyzed using SPM2 software (SPM2; Welcome Department of Cognitive Neurology, UK). The EPI images for each time series were realigned with reference to the first image to correct for head motion. The anatomical images were co-registered with the mean functional images and normalized to the Montreal Neurological Institute (MNI) brain template. Functional data were then normalized using the same transformation parameters and were smoothed in the spatial domain (isotropic Gaussian kernel of 8 mm full width half maximum, FWMH).

Statistical analyses were based on general linear model and activations were modeled using a simple delayed box- car reference vector convolved with a hemodynamic response function (HRF). Low-frequency drifts were removed using a high-pass filter (Holmes *et al.*, 1997) and a first order autoregressive model (AR1) (Friston *et al.*, 2000) was applied for eliminating the temporal autocorrelation of the fMRI time-series data.

Results

Behavioral Results Inside the Scanner

The reaction times for making judgments about the degree of match between the word and the locomotion during the scanning were analyzed. The results indicated that the reaction times for the judgments did not differ across the three word classes, $F(2,20)=0.272$, $p>0.05$.

We also checked if the judged degree of match between the word and locomotion itself differed across the three word classes. No differene was found among mimetics, verb, and adverb conditions.

These results together with the results of the pre-scanning rating studies suggest that the three types of words did not differ in the task difficulty. Hence, if we see differences in the pattern of activations across the three word classes, it cannot be attributed to the task difficulty or processing difficulty of the words.

f-MRI Results

Activation pattern for each word class compared to the baseline

To identify the areas of activation due to processing each type of words, the gross activation for the mimetic, adverb, and verb condition[1] was subtracted by the activation obtained from the motion only (without words) control[1]. The usual left hemisphere dominance was observed for the adverbs and verbs. It is important to note that, for all word types including the verbs and adverbs, after removing the activation responsible for perceptual processing of locomotion video, the activation of the motor-premotor areas was identified. This result suggests that, whether the word is sound symbolic or not, words are anchored to direct perceptual/sensory experiences, in keeping with the embodiment view of concepts and word meanings (e.g., Barsalou et al., 2003, Kemerer, 2010) and in contrast to the formal view of language, which asserts that words are arbitrary symbols.

Interestingly, processing of the mimetic words elicited much broader and stronger activation of the brain than verbs and adverbs. In particular, extensive bi-hemispheric activations were observed when the mimetic word was processed together with the locomotion video, consistent with our hypothesis that mimetic words have dual natures, both as linguistic and non-linguistic gesture-like symbols (Figure 1). Note that the difference between the mimetic words and the other two types of words could not be attributed to familiarity or task difficulty, because the results of pre-ratings and the behavioral results inside the scanner found no difference across them.

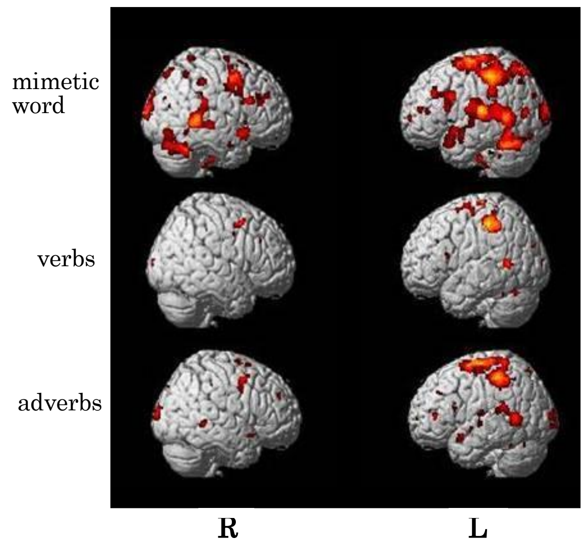

Figure1. Unique activations for each word class. The activation map is overlaid onto a rendered SPM normalized brain. Height threshold at p<0.001, uncorrected and 0 voxel extend threshold for one sample t-test were applied).

Unique areas of activation for each type of words

Next we examined the unique areas of activation for verbs, adverbs, and mimetic words. For this purpose, the activations observed for the target word class was subtracted by the other two word classes. For example, in order to see the unique regions for the mimetic words, the activations observed for the verbs and adverbs were subtracted from the activations elicited in the mimetic condition.

As is clearly seen in Figure 2, the verb and the adverbs showed virtually no unique regions left, when the activations for mimetics processing were subtracted. In contrast, as expected, activations of the bilateral STG/STS and the MT areas were shown as the specific regions for the mimetics. Also, the mimetics elicited stronger and broader activation in

[1] Here, we only used the blocks of the "natural" motion because we use only "natural" motions for the main experiment. The data from the unnatural motion blocks were discarded from the analysis.

the motor and pre-motor regions than the verbs and adverbs (Figure 2). This finding further supports the hypothesis that mimetic words are more strongly tied to sensory experience than non-sound symbolic verbs and adverbs, and that cross-domain integration between auditory and other (e.g., motor and motor perception) sensory domains are particularly important for processing of mimetic words.

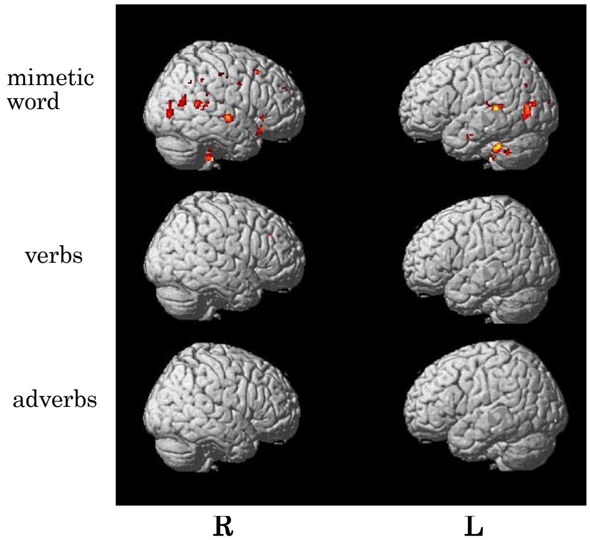

Figure2. The specific regions identified for each word class. The activation map is overlaid onto a rendered SPM normalized brain. Height threshold at p<0.001, uncorrected and 3 voxel extend threshold for one sample t-test were applied).

Correlation between the strength of activation and the degree of semantic match

We further examined if the pattern of brain activity varied as a function of the word-video match or mismatch. The strength of activation in the motor, premotor, and STS areas was correlated with the degree of word-locomotion match. This analysis revelaed that when the meaning of mimetic words matched the locomotion, the right motor area was activated more strong (r =.554, p <.05); when they did not match, the right pre-motor area was activated (r =.-555, p <.05) (Figure 3).

The shift of the areas of activation between the motor and pre-motor regions along with the change in the degree of the mimetic-locomotion match was intriguing: When the locomotion and the mimetic word semantically matched, the participants presumably mimicked the action easily in the brain; but if the mimetic word and locomotion did not match, the participants might have tried to model the action themselves, and as a result, the activation shifted to the primotor area. In contrast, no such correlation was found in the right STG/STS area, suggesting that the activation of the right STS region was related to the processing of mimetic words per se, independent of whether the word semantically matched the motion or not.

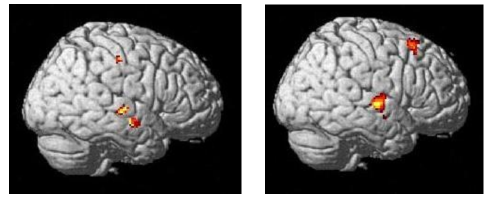

Figure3. The activations in the right hemisphere as a function of matching (Left) and mismatching (Right) mimetic words. The activation map is overlaid onto a rendered SPM normalized brain. Height threshold at p<0.001, uncorrected and 0 voxel extend threshold for ANOVA were applied).

Discussion and Conclusion

This research investigated the neural representation of mimetic words, verbs and adverbs in the domain of human locomotion using fMRI. In the traditional formal linguistics, sound symbolism has been considered as an unimportant aspect of language (e.g., Saussure, 1986; Sapir, 1921). However, recently, this view has been revisited in linguistics, psychology, language development, and neuroscience.

Researchers have demonstrated that certain phonological and prosodic properties are correlated with the meanings of words (e.g., voicedness are correlated with heaviness), and that people are able to detect this sound-meaning correlates from very early developmental stages (e.g., Maurer and Mondoch, 2005). It has also been suggested that sound symbolism may play a role in language development within a child (Imai et al., 2008; Kita et al., 2010) as well as evolution and origin of language (Ramachandran & Hubbard, 2005). In spite of the accumulating evidence for the presence of universal sensitivity to the sound-meaning correspondence, the neural mechanism behind it has been still at a stage of speculation.

This research was conducted to uncover the neural mechanism of sound symbolism by comparing the activation patterns for sound-symbolic mimetic words, (non-sound symbolic) verbs and adverbs in the domain of locomotion. The results largely support the hypothesis that mimetic words have dual natures, somewhat in between linguistic symbols and non-linguistic gesture, as not only the regions relevant to language processing but also those relevant to non-linguistic iconic gestures were activated. The stronger activation of the MT, motor and pre-motor areas also suggest that mimetic words invoke stronger attention to the motion and invites speakers to mentally simulate the action more strongly than regular, non-sound symbolic verbs.

Ramachandran and Hubbard (2005) speculate that processing of sound symbolic words involves cross-domain mappings in the brain between sound contours and motor patterns. The bilateral activation of the STS area found for the mimetic word processing strongly indicates cross-domain mappings and integration between sound and motion, and provide support for their speculation. In future research, it is important to see if the pattern is replicated for mimetic words expressing other sensory domains (e.g., touch).

The results are also in great harmony with the embodiment view of language and cognition, demonstrating that words in general invoke activations of relevant sensory areas, consistent with previous neuro-imaging studies (e.g. Martin et al, 1995; Huak & Pulvermüller, 2004; Kemmerer& Tranel, 2008). However, they also suggest that the degree of embodiment depends on word types, with highly sound- symbolic words like mimetic words are most directly and strongly bound to sensory experience.

The issue of the origin of the sensitivity to sound symbolism is extremely interesting. Maurer and Mondoch speculate that sensitivity to sound symbolism is universally present prior to language learning, reasoning that it occurs as a bi-product of over-connectivity among different sensory areas in infants. In our lab, we are currently testing whether pre-semantic infants are sensitive to the sound-vision (shape) correlates and how this can be manifested in the brain. This may open the door to the big quest concerning the origin of language.

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