4 Neural Substrates of Sensitivity to Affective Meaning

Hideaki Kawabata[1] *and Jiro Gyoba*[2]

[1] Department of Psychology, Keio University
[2] Department of Psychology, Tohoku University

1. Introduction

Environmental information that reaches our sense organs arouses a variety of attitudes, impressions and affective responses. We may express affective responses to sensory information with simple adjectives such as “beautiful”, “soft”, “cold”, or “mild”. In fact, one of the best-known and most effective techniques used to measure affective responses is the semantic differential (SD) technique (Osgood, Suci, & Tannenbaum, 1957), in which subjects are asked to rate affective meanings for objects or materials using 10 to 30 pairs of contrary adjectives (e.g., *good-bad*).

To clarify the relationships among various adjective pairs in semantic space, we normally perform a factor analysis for the rating data to find principle factors underlying determinants of semantic space that are used to express affective responses to objects, concepts and phrases. These principle factors comprise a psychological foundation for specific characteristics of attitudes, impressions, and affective responses to objects, concepts and phrases. Using factor analysis, three factors are often extracted irrespective of the kinds of objects used or the cultural backgrounds of the participants; these are *Evaluation, Activity, and Potency* (Osgood, 1960).

Previous psychological studies employing the SD technique have indicated that affective meanings of sensory stimuli might depend on the sensory relevance of each adjective pair (e.g., visual, auditory, tactile, or olfactory) (Suzuki & Gyoba, 2003; Suzuki, Gyoba, Kawabata, Yamaguchi, & Komatsu, 2006). Adjective pairs belonging to *Activity* often involve auditory perception, such as dynamic-static, excitable-calm, and noisy-silent (Oyama, Yamada, & Iwasawa, 1998; Suzuki, & Gyoba, 2003; Suzuki, Gyoba, & Sakuta, 2003; Takahashi, 1995), whereas those belonging to Potency are often associated with somatosensory or tactile perception, such as soft-hard, smooth-rough, and blunt-sharp (Suzuki & Gyoba, 2003; Takahashi, 1995). *Evaluation*, meanwhile, includes adjective pairs related to subjective evaluation and preference, such as good-bad, beautiful-ugly, and pleasant-unpleasant. This factor therefore does not depend on sensory relevance (see Suzuki et al., 2006).

In the present paper, we introduce recent advances in studies concerning the neural substrates of sensitivity to affective meaning examined using a variety of stimulus types and brain imaging techniques. We aimed to clarify the brain mechanism(s) that correlates with affective meaning.

2. Event-related potentials

Previous investigations of the neural substrates of affective evaluation have been performed primarily using event-related potentials (ERPs). These studies have examined brain activity corresponding to three main factors of the affective meaning of words, and determined the differences among the main factors.

Chapman, McCrary, Chapman, & Martin (1980) examined ERPs during the recognition of word stimuli, in which visual word stimuli were categorized into semantic classes as one of three factors (i.e., *Evaluation, Activity*, or *Potency*) and subjects were asked to judge each word stimulus on a semantic scale. The authors found that different ERP patterns were obtained in each semantic class, and that the ERP patterns observed while subjects were rating a word were similar to those observed when reading the word aloud. Skrandies (1998), in order to examine ERP responses related to the affective meaning of words, collected visual word stimuli to be categorized as three semantic difference factors (i.e., *Evaluation*, *Activity*, or *Potency*) and two polarities (i.e., *positive*-polarity or *negative*-polarity) based on a preliminary experiment conducted before the main ERP experiment. In that study, differences among the three factors were apparent even at early latencies at 80-260 ms after stimulus onset (see also Skrandies & Chiu, 2003). For example, Global Field Power (GFP) had a *positive* polarity for words in Evaluation, but a *negative* polarity for words in Activity and *Potency*, at 130- to 195-ms temporal latencies (Skrandies, 1999). In addition to examination of such temporal characteristics, ERP studies have demonstrated significant differences in scalp topography—i.e., brain activity (i.e., electric potentials) for *Potency* was located more anteriorly or posteriorly than that for *Evaluation* and *Activity*, depending on the polarity of the adjective pair scales.

Thus, affective meaning related to three factors (*Evaluation*, *Activity*, or *Potency*) extracted by the SD technique might reflect distinct neural mechanisms, and differences among these factors might emerge even at early temporal latencies. Although the temporal resolution of ERPs is indeed high, the spatial resolution obtained from ERPs is not sufficient to identify the brain areas that can produce neural activities (Pascual-Marqui, Esslen, Kochi, & Lehmann, 2002).

3. Near-infrared spectroscopy (NIRS)

Rather than ERP measurement, recent studies have used near-infrared spectroscopy (NIRS), an optical technique that can easily measure localized cortical brain activities, to investigate the brain topology of cortical responses related to the affective meaning of sensory stimuli. For example, Suzuki, Gyoba, and Sakuta (2003, 2005) measured brain activity while participants rated line drawings on bipolar adjective pair SD scales. The authors reported that *Activity* and *Potency* correlated to the activities of the auditory association cortex involving the right superior temporal gyrus (STG), while the left pre- and postcentral gyrus related to somatosensory (tactile) information processing. Previously, many studies employing the SD technique have reported that adjective scales related to *Activity* often refer to auditory perception, such as dynamic-static, excitable-calm, and noisy-silent (Oyama et al., 1998; Suzuki & Gyoba, 2003; Suzuki et al., 2003; Takahashi, 1995). On the other hand, *Potency* in judging line drawings often involves adjective pairs related to somatosensory or tactile perception, such as soft-hard, smooth-rough, or blunt-sharp (Suzuki & Gyoba, 2003; Takahashi, 1995). These findings suggest that the specific factors underlying affective meaning depend on the sensory relevance of each adjective pair (e.g., visual, auditory, tactile, olfactory) (Suzuki & Gyoba, 2003; Suzuki et al., 2006). *Evaluation* produced no specific brain activity in NIRS measurements. One reason why no significant brain activity is observed for *Evaluation* may be that NIRS measurements are limited to activity of the brain surface (Hoshi, 2005). Brain activity related to *Evaluation* may be found in deeper areas, such the amygdala, insula, orbitofrontal cortex, or anterior cingulate cortex (e.g., Kawabata & Zeki, 2004). Moreover, brain activity correlated with *Evaluation* is likely to include subjective emotional properties that are not dependent upon sensory processing or modalities (Suzuki et al., 2005). Therefore, in order to clarify the neural responses related to affective meaning, particularly in *Evaluation*, we must conduct experiments using functional magnetic resonance imaging (fMRI), which can be used to obtain brain activity maps corresponding to perceptual, cognitive or motor function.

4. Functional magnetic resonance imaging (fMRI)

Recently, Schaefer and Rotte (2010) investigated the connotative meanings of brands (e.g., ‘Aspirin’) using the SD technique in combination with fMRI. They showed increased activity in the medial prefrontal cortex for “social competence”, which may correspond to *Evaluation*, and decreased activity in the superior frontal gyrus for *Potency*. The authors reported that only these two factors were extracted from the rating data. Therefore, it remains unclear how these brain activities are associated with the three factors generally extracted in studies using the conventional SD technique.

As mentioned above, previous ERP studies concentrated mainly on the temporal aspects of brain activation in relation to the three factors of affective meaning extracted using the SD technique, while previous NIRS studies mapped brain activities on the surface of the cerebral cortex corresponding to these factors (particularly *Activity* and *Potency*). However, even with fMRI, Schaefer and Rotte (2010) could identify only brain activities aroused by Evaluation and Potency. Thus, neuroimaging studies have not yet shown consistent evidence of brain activity corresponding to the three main factors.

In the following sections of this paper, we introduce our recent findings obtained from fMRI studies, in which we investigated brain activity during SD ratings of line drawings and *haiku* poems, in order to obtain a deeper understanding of affective meaning aroused by visual objects or word stimuli.

IV. 1. An fMRI study investigating brain activity related to affective meaning in reaction to line drawings

We examined the brain areas activated in response to the three main factors underlying the affective meaning of line drawing stimuli using fMRI (Kawachi, Kawabata, Suzuki, Shibata, & Gyoba, submitted). Twenty participants viewed 27 line drawings in an MRI scanner, and were asked to rate each drawing (presented for 6 sec) using nine adjective pairs on a three-point scale (e.g., 1, good; 2, indifferent; 3, bad) in different trials. A total of 243 trials (nine adjective pairs (three items for three SD factors) times 27 line-drawings) were carried out. The results showed that subjective ratings that were determined in conjunction brain activation among three factors produced significant brain activity in the amygdala, bilateral inferior frontal gyrus (IFG), left middle frontal (orbitofrontal) gyrus, bilateral primary visual cortex, and left precentral gyrus. These activities show general affective responses by subjective ratings. We also identified increasing activities for each factor by testing for greater activity in *Evaluation*, *Activity*, or *Potency* as compared to the other two factors. In particular, the right inferior frontal gyrus (IFG) was activated for *Evaluation*, and the activity increased for *positive* polarity (rated as “beautiful,” “pleasant,” or “clear”) compared to that for *negative* polarity (rated as “ugly,” “unpleasant,” or “cloudy”). Moreover, the left superior temporal gyrus (STG), which was activated for *Activity*, showed decreased brain response for *negative* polarity (rated as “calm,” “static,” or “sober”) as compared to that for *positive* polarity (rated as “excitable,” “dynamic,” or “gay”). The right superior frontal gyrus (SFG) was activated for *Potency* showed decreased brain response for negative polarity (rated as “soft, ” “blunt,” or “smooth”) compared to those positive polarity (rated as “hard,” “rough,” or “sharp”). These results show that, using fMRI combined with the SD technique, three factors (*Evaluation*, *Activity*, and *Potency*) underlying different affective meanings were distributed in distinct parts of the brain.

IV.2. Brain activities associated with affective meaning in reaction to haiku poems

In the last section of this paper, we briefly introduce one more recent study in which we used *haiku* poem stimuli. *Haiku*, a poetic form that originated in Japan, is known as the shortest type of poetry in the world; it consists of 5, 7, and 5 characters in Japanese, or an equal number of syllables in other languages. Traditionally, *haiku* are intended to arouse the imagination of readers, evoking the senses of sight, hearing, touch, and even smell and/or gesticulation rather than establishing a concrete meaning. Using *haiku* poems as stimuli, we measured brain activity corresponding to three main factors underlying affective meaning extracted by the SD technique, and compared the topographic distributions of brain activity among the factors (Kawabata, Kawachi, Shibata, Suzuki, & Gyoba, in submission). Nineteen participants (12 females) read 18 haiku poems presented in an MRI scanner, and were asked to rate each poem using nine adjective pairs on a three-point scale (e.g., 1, ugly; 2, indifferent; 3, beautiful) in different trials. Factor analysis (principal factor method) was conducted for the subjective rating data in the MRI scanner, extracting three varimax-rotated factors: *Evaluation* (including “ugly-beautiful,” “unpleasant-pleasant,” and “cloudy-clear”), *Activity* (including “calm-excitable,” “sober-gay,” and “static-dynamic”), and *Potency* (including “soft-hard,” “smooth-rough,” and “relaxed-tense”). The factorial structure underlying the affective meaning aroused by *haiku* poems was similar to that reported in previous studies using line drawings (Suzuki & Gyoba, 2003; Takahashi, 1995). General activation among the three factors was located in the primary visual cortex (V1) and the amygdala. *Haiku* stimuli composed of words were visually presented to each participant, indicating clear activity in the primary visual area. A previous report indicated that the amygdala could be related to subjective judgments of affective feelings and impressions (Dalgleish, 2004). Brain activity showed differential distributions among the three factors. One of the most activated areas in *Evaluation* was the IFG, extending to the lateral orbitofrontal cortex and amygdala, which agrees with previous findings (Kawachi et al., in submission). Brain activity related to *Evaluation* is reportedly linked to affective judgment and hedonic experience (e.g., Kringelbach, 2005). In contrast, *Activity*-dependent brain activity was limited to the bilateral middle frontal gyrus (MFG). For *Potency*, the left middle frontal gyrus, left amygdala, and left middle frontal gyrus were activated. Although these activated areas were not discussed in previous reports, these might be related to sensory processing; for example, the MFG is involved in acoustic sensory processing and supplemental motor processing in the brain.

5. Conclusion

Using fMRI combined with the SD technique, we identified the areas of brain activity corresponding to three different factors extracted by factor analysis from rating data of the SD technique. We examined brain activity corresponding to three psychological structures (*Evaluation*, *Activity*, and *Potency*) underlying participants' ratings of line drawings using adjective pair scales. Thee present findings may represent a step toward better neuroscientific understanding of affective impressions and may help to answer the question of how these diverse affective impressions are represented in the brain. Previous studies utilizing SD techniques have reported that these psychological structures have been found across various stimulus domains (e.g., Osgood et al., 1957). Further exploration, using fMRI in combination

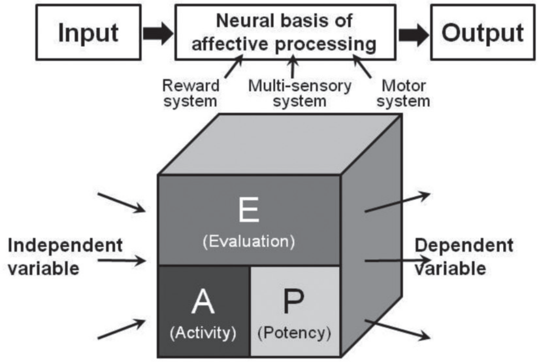

Figure 1. Diagram for processing of three factors underlying affective meaning.

with SD techniques, is warranted to improve understanding of the commonalities and differences in the spatial distribution of brain areas corresponding to psychological structures underlying affective meaning relating to words, music, or multimodal art.

Here, we would like to return to the description of Osgood (Osgood, 1960), who proposed that the three factors extracted using the SD technique might correspond to distinct parts of the brain, and, more specifically, that affective meaning might be processed in the hypothalamus, the reticular nucleus and other areas of limbic system, and the frontal cortex. Even today, 50 years later, Osgood's inference is not completely wrong. Our fMRI results support part of Osgood's idea—that is, sensitivity to affective meaning in the brain varies according to the three factors of *Evaluation*, *Activity*, and *Potency* (Figure 1).

References

Chapman, R. M., McCrary, J. W., Chapman, J. A., Martin, J. K. (1980). Behavioral and neural analyses of connotative meaning: word classes and rating scales, *Brain and Language*, 11, 319–339.

Dalgleish, T. (2004). The emotional brain. *Nature Reviews Neuroscience*, 5, 583–589.

Hoshi, Y. (2005). Functional Near-Infrared Spectroscopy: Potential and Limitations in Neuroimaging Studies. *International Review of Neurobiology*, 66, 237–266.

Kawachi, Y., Kawabata, H., Kitamura, S. M., Shibata, M., & Gyoba, J. (in submission) Topographic distribution of brain activities corresponding to psychological structures underlying affective meanings: An fMRI study.

Kawabata, H., Kawachi, Y., Kitamura, S. M., Shibata, M., & Gyoba, J. (2008) Distributions of neural activities corresponding to psychological structure underlying the impressions of Haiku poems. *IEICE technical report: Neurocomputing*, 108 (264), 31–34. (In Japanese)

Kawabata, H., & Zeki, S. (2004). Neural correlates of beauty. *Journal of Neurophysiology*, 91, 1699–1705.

Kringelbach, M. L. (2005). The human orbitofrontal cortex: linking reward to hedonic experience. *Nature Reviews Neuroscience*, 6, 691–702.

Osgood, C. E., Suci, G., & Tannenbaum, P. H. (1957). *The Measurement of Meaning*. Urbana: University of Illinois Press.

Osgood, C. E. (1960). The cross-cultural generality of visual-verbal synesthetic tendencies. *Behavioral Science*, 5, 146–169.

Oyama, T., Yamada, H., Iwasawa, H. (1998). Synesthetic tendencies as the basis of the sensory symbolism: a review of a series of experiments by means of semantic differential. *Psychologia*, 41, 203–215.

Pascual-Marqui, R. D., Esslen, M., Kochi, K., & Lehmann, D. (2002). Functional imaging with low resolution brain electromagnetic tomography (LORETA): review, new comparisons, and new validation. *Japanese Journal of Clinical Neurophysiology*, 30, 81–94.

Schaefer, M., & Rotte, M. (2010). Combining a semantic differential with fMRI to investigate brands as cultural symbols. *Social Cognitive & Affective Neuroscience*, 5, 274–281.

Skrandies, W. (1998). Evoked potential correlates of semantic meaning: a brain mapping study, *Cognitive Brain Research*, 6, 173–183.

Skrandies, W. (1999). Early effects of semantic meaning on electrical brain activity, *Behavioral and Brain Science*, 22, 301–302.

Skrandies, W., & Chiu, M. J. (2003). Dimensions of affective semantic meaning – behavioral and evoked potential correlates in Chinese subjects, *Neuroscience Letters*, 341, 45–48.

Suzuki, M., & Gyoba, J. (2003). Analyzing the factor structure and the sensory-relevance of impressions produced by words and drawings, *The Japanese Journal of Psychology*, 73, 518–523.

Suzuki, M., Gyoba, J., Kawabata, H., Yamaguchi, H., & Komatsu, H. (2006). Analyses of the sensory-relevance of adjective-pairs by the modality differential method. *The Japanese Journal of Psychology*, 77, 464–470.

Suzuki, M., Gyoba, J. & Sakuta, Y. (2003). Multichannel near-infrared spectroscopy analysis of brain activities during semantic differential rating of drawings, *Tohoku Psychologica Folia*, 62, 86–98.

Suzuki, M., Gyoba, J. & Sakuta, Y. (2005). Multichannel NIRS analysis of brain activity during semantic differential rating of drawing stimuli containing different affective polarities. *Neuroscience Letters*, 375, 53–58.

Takahashi, S. (1995). Aesthetic properties of pictorial perception, *Psychological Review*, 102, 671–683.