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Research report

The inversion effect in visual word form processing

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ABSTRACT

Reading is one of the best well-practiced visual tasks for modern people. We investigated how the visual cortex analyzes spatial configuration in written words by studying the inversion effect in Chinese character processing. We measured the psychometric functions and brain activations for upright real-characters and non-characters and their inverted (upside down) versions. In the psychophysical experiment, the real-characters showed an inversion effect at both 1° and 4° eccentricities, while the non-characters showed no inversion effect for all eccentricities tested. In the functional magnetic resonance image (fMRI) experiment, the left fusiform gyrus and a small area in the bilateral lateral occipital regions showed a significant differential activation between upright and inverted real-characters. The bilateral fusiform gyri also show differential activation between upright real- and non-characters. The dorsal lateral occipital regions showed character-selective activation when compared with scrambled lines. The result suggested that the occipito-parietal regions may analyze the local features of an object regardless of its familiarity. Therefore, the lateral occipital regions may play an intermediate role in integrating the local information in an object. Finally, the fusiform gyrus plays a critical role in analyzing global configurations of a visual word form. This is consistent with the notion that the human visual cortex analyzes an object in a hierarchical way.

1. Introduction

Reading may be one of the most well-practiced visual tasks for a person living in a modern society. It is very likely that a reader may have read hundreds of millions of words in his or her lifetime. For instance, skilled Chinese readers can, on average, read about 600 characters per minute (Sun et al., 1985). Assume that a 20-year-old college student, since the fourth grade, has spent only two hours per day reading at half of his or her top reading speed. This student would have read 300 char/min × 120 min/day × 3650 days = 1.3×10^8 characters in just 10 years. With this amount of practice, our visual system may have developed an efficient way to process word information.

It is suggested that, to perform a well-practiced visual task, such as recognizing a face, the visual system tends to analyze the configuration, or spatial relationship among image elements, rather than the image elements themselves (Tanaka and Farah, 1993). At the behavioral level, such configurational processing is best manifested in the inversion effect (Diamond and Carey, 1986; Ying, 1969). In the inversion effect, an observer has more difficulty recognizing an object in a picture when the image is placed upside down than when the image is in the upright position. Since the image elements

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in the upright and the inverted images are the same and only the spatial relationship among image elements is changed by the inversion, such impairment of performance implies a mechanism for analyzing spatial configurations whose function is disrupted by the image inversion. Such an inversion effect has been found in recognizing human faces in normal populations (Carey and Diamond, 1977; Leder and Bruce, 2000; Rhodes et al., 1993; Ying, 1969), recognizing dogs by dog training experts (Diamond and Carey, 1986) and recognizing novel objects by observers trained to identify those objects (Gauthier and Tarr, 1997).

In this study, we investigated the spatial configuration processing of orthographic objects using Hanzi, also called ''Chinese characters'' in some literature. Hanzi, pronounced as Kanji in Japanese, is a set of characters used in several East Asian written languages. There is behavioral evidence of spatial configuration processing in Hanzi. It showed that skilled readers of Hanzi (e.g., Taiwanese or Japanese college students) tended to sort Hanzi with similarities in global spatial relationships among character components, while non-readers (e.g., American college students) tended to sort Hanzi with similarities in character components (Yeh and Li, 2002; Yeh et al., 2003).

There may be two ways to analyze spatial configurations in a Hanzi character. First, the visual system may analyze the spatial configurations in a hierarchical way. A character is composed of several character components and each of these components is composed of several strokes. Hence, the analysis of spatial configurations may occur on both levels: one is concerned with the spatial relationship among strokes in a character component, while the other is concerned with the spatial relationship among components in a character. For the purpose of this discussion, we will refer to the former as the local configuration and the latter as the global configuration. Second, the visual system may directly analyze the spatial relationship of the strokes relative to the whole characters. Hence, character components are just a set of strokes and play only a small role in spatial configuration processing.

To make distinctions among possible types of configuration processing, in this study we use only characters that are semantic–phonetic composites. About 90% of frequently used characters are of this type (DeFrancis, 1984). These characters are composed of two components, arranged in a left–right global configuration (see Fig. 1a for an example). The spatial configurations of a character were manipulated in the following ways: first, we swapped the position of the left and right components of a character as shown in Fig. 1b. This manipulation altered the global configuration but left the local configuration intact. For semantic–phonetic composites, this left–right swapping is the same as the construct of ''non-characters'' referred to in some literature (Hue and Tzeng, 2000). Thus, to be consistent with previous studies, we will identify the original characters as real-characters and the left–right swapped characters as ''non-characters''. We then inverted both real-characters and non-characters to disrupt both local and global configurations (Fig. 1c and d).

There are studies using mirror reversed words (Dong et al., 2000; Poldrack et al., 1998; Proverbio et al., 2007; Ryan and Schnyer, 2007). At first glance, such manipulation is similar to ours. However, those studies focused on skill learning and did not address the issue of the visuospatial analysis of the stimuli. As a result, while they showed extensive occipito-temporal activation in the mirror reading tasks, these studies failed to analyze or separate the functions of different loci of activation in the occipitotemporal cortex during word processing.

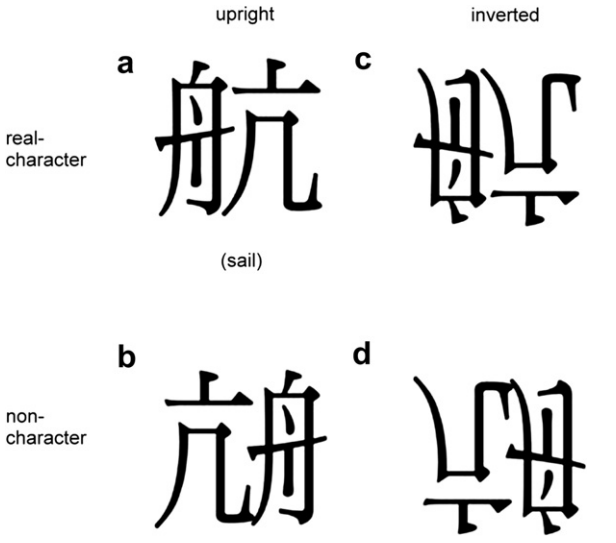

Fig. 1 – Examples of the stimulus types used. (a) An upright real-character; (b) an upright non-character; (c) an inverted real-character; (d) an inverted non-character.

While the inversion effect has been demonstrated in several categories of objects, to the best of our knowledge, it has not been reported for Chinese words or characters. Therefore, we first demonstrated an effect with a psychophysical experiment by showing an impairment of the discrimination performance for inverted real-characters, compared with that for upright real-characters. In addition, it is reported that the inversion effect may have different properties for foveal and peripheral presented stimuli (McKone, 2004; McKone et al., 2007). We, therefore, also tested the inversion effect at the parafoveal and the peripheral eccentricities. We then investigated the cortical activation for spatial configurations in Hanzi. The cortical areas that are sensitive to all spatial configurations should show an inversion effect for real-characters. Furthermore, the areas that are sensitive to the global configurations should show the differential activation between real- and non-characters. The areas that are sensitive to the local configurations should show an inversion effect for non-characters.

2. Methods

2.1. *Psychophysics*

2.1.1. *Participants*

Twelve right-handed observers (6 males, 6 females) between 20 and 24 years old were participated in this study. All participants were undergraduate or graduate students at the National Taiwan University. They are all fluent in reading