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Research Report

Short-term language experience shapes the plasticity of the visual word form area

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ABSTRACT

Previous studies have identified a region in the left fusiform gyrus that responds selectively to visual words, termed the visual word form area (VWFA). Converging evidence from neuropsychological, electrophysiological, and functional neuroimaging studies suggests that the VWFA is wired up largely by long-term experience because it responds specifically to words and letter strings only in an orthography a subject knows. However, it is less clear whether the plasticity of the VWFA can be modulated by short-term language experience. Here, we used functional magnetic resonance imaging (fMRI) to address this question by examining whether the representation for novel stimuli could be constructed in the VWFA after a short-term language experience. In particular, we trained subjects to associate a set of novel stimuli with English letters. We found that VWFA response to the trained stimuli was significantly higher than that of untrained stimuli after 3 days of association training. This learning-induced change in neural activities was absent in other specialized cortical areas involved in face perception or in processing object shapes. Multivariate pattern analysis further revealed that the learning-induced representation engaged the same neural population underlying the representation for language forms constructed through long-term experience. Our study clearly illuminates that the plasticity of the VWFA can be shaped by short-term language experience, bridging the gap between short-term and long-term experiences in language learning.

1. Introduction

Numerous human neuroimaging (Baker et al., 2007; Dehaene et al., 2001, 2004; Glezer et al., 2009; Kronbichler et al., 2004; Vinckier et al., 2007) and neuropsychological studies (Cohen et al., 2003; Gaillard et al., 2006) have identified a cortical region in the left occipitotemporal cortex, termed the visual word form area (VWFA) (Cohen et al., 2000, 2002). This area is not sensitive to low-level properties of visual words, such as size, position, font, or letter case (Cohen et al., 2000; Dehaene et al., 2004; McCandliss et al., 2003; Polk and Farah, 2002; but see Barton et al., 2009). Instead, it responds very specifically to

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Abbreviations: BOLD, blood oxygen level-dependent; EPI, echo-planar imaging; FFA, fusiform face area; fMRI, functional magnetic resonance imaging; FWHM, full-width at half-maximum; GLM, general linear model; LO, lateral occipital cortex; MVPA, multivariate pattern analysis; ROI, region of interest; RT, reaction time; VWFA, visual word form area

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words and letter strings only in orthography a subject knows (Baker et al., 2007). These findings suggest that the VWFA is mainly involved in processing the shape of language forms that we have learned in the past. However, it is less clear whether the plasticity of the VWFA is subject to the modulation of the short-term language experience. In this study, we instructed subjects to learn the associations between a set of novel stimuli and English letters for 2 to 3 days. We then examined whether the representation for the trained stimuli was constructed in the VWFA and investigated the tolerance of the representation to phonological and semantic manipulations.

Converging evidence from electrophysiological and functional neuroimaging studies has demonstrated that the selectivity of the VWFA largely originates from extensive experience with visual words. The word-selective N1, presumably generated by the VWFA, was absent in illiterate kindergarten children and was present after they learned how to read (Maurer et al., 2006). The developmental change in latency of the N1 further extends to adolescence (Brem et al., 2006). Consistently, in an fMRI study, children's reading skills are positively correlated with the neural activity in the left occipitotemporal cortex, where the VWFA resides (Shaywitz et al., 2002). In adults, a recent fMRI study found that the VWFA responds more strongly to Hebrew words in Hebrew-readers than in non-Hebrew-readers (Baker et al., 2007). Taken together, the findings from previous studies have consistently demonstrated that the VWFA must be wired up largely by long-term experience.

However, it is less clear whether short-term language experience is sufficient to construct word representation in the VWFA. The results from existing neuroimaging literature on the plasticity of the VWFA under short-term language experience are controversial, with some showing increased responses to trained stimuli in the occipitotemporal cortex (Deng et al., 2008; Xue et al., 2006), some showing decreased responses (Breitenstein et al., 2005; Sandak et al., 2004), and others showing no significant effect on language learning (Bitan et al., 2005; Hashimoto and Sakai, 2004; McCandliss et al., 1997). These apparently inconsistent results may result from the following reasons. First, most studies, if not all, used as training stimuli natural language forms that subjects did not know (e.g., Breitenstein et al., 2005; McCandliss et al., 1997; Sandak et al., 2004). It is possible that subjects had already been exposed to the to-be-trained language forms to some extent, and unsupervised learning as a consequence of passive exposure might have occurred (e.g., Fiser and Aslin, 2001; Purves et al., 2001; Rosenthal et al., 2001). Even if the to-be-trained language forms were completely novel to subjects, the inherent orthographic structure of natural language forms may bias the visual system to develop representations in the VWFA in a bottom-up stimulus-driven fashion, independent of the top-down language experience from the training. This is clearly demonstrated in a recent fMRI study (Op de Beeck et al., 2006) in which increased responses to novel nonface objects that looked like "women with a hat" are observed in the fusiform face area (FFA) (Kanwisher et al., 1997), but not in regions involved in analyzing the shape of nonface objects (i.e., the lateral occipital cortex, LO) (Grill-Spector et al., 2001; Grill-Spector, 2003). Second, most studies did not independently localize the VWFA. Therefore, it is unclear whether learning-induced changes in neural activities occur within the VWFA or within other regions specialized in processing the shape of nonword objects. In addition, even if the learning effect does occur within the VWFA, it is possible that two overlapped but functionally independent neural populations are involved in processing the language form learned through short-term experience and that learned through long-term experience.

In this study, we designed a set of novel figures that bear no resemblance to daily objects or natural language forms (Fig. 1A). We then used an association learning paradigm to train subjects to learn associations between these figures and English letters (Fig. 1B). After behavioral training, we used fMRI to independently localize the VWFA as a region of interest (ROI), and then examined whether the representation for the trained stimuli was constructed within the VWFA. Multivariate pattern analysis (MVPA) was further used to examine whether the representation for the trained stimuli engaged the same neural population that represented English words and Chinese characters learned through long-term experience. We found that short-term language experience was sufficient to construct the representation for the trained stimuli in the VWFA; interestingly, the representation engaged the same neural population for English words but not for Chinese characters. In addition, the representation was insensitive to phonological or semantic aspects of the trained stimuli, suggesting that the representation is shape-based, similar to word representations constructed through long-term experience. Taken together with the results of previous studies, our study suggests that the plasticity of the VWFA can be shaped by short-term experience in the same way as long-term experience.

2. Results

2.1. *Behavioral results*

The stimuli used in behavioral training were line-drawing abstract figures constructed from simple shapes (e.g., arc, line, circle, and square). They were designed to seem novel so as not to immediately suggest associations with everyday objects or language forms. Sixteen figures were randomly chosen from a figure pool and were paired with 16 English letters or letter strings to form 16 paired associates (i.e., stimulus pairs) (Fig. 1A).

Subjects were trained to learn the paired associates of novel figures and English letters in a paired-associate association learning task, where they were instructed to judge whether the simultaneously presented figures and English letters were the actual paired associates (Fig. 1B). As shown in Fig. 1C, association learning greatly improved behavioral performance in both accuracy and reaction time (RT). The accuracy reached ceiling in the first session and remained above 90% during the entire training period, suggesting that the stimulus pairs were learned quickly and accurately. Meanwhile, the time required to judge whether simultaneously presented stimulus pairs were correct pair associates decreased monotonically from session 1 to session 6 ($F(5, 45) = 9.53$, $p < 0.001$) and then reached asymptote from session 7 to session 10 ($F(3, 27) < 1$).