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Different activity patterns for action and language within their shared neural areas: An fMRI study on action observation and language phonology

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ABSTRACT

The neural processes for action and language activate shared brain regions including the left inferior frontal, parietal and temporal-occipital cortices. However, it still remains unclear how action and language are related and what neural activity patterns are elicited within these shared cortical regions. In this study we examined the neural activation for action observation and language phonology in their shared cortical regions by conducting three experiments in a single fMRI session: a mixed-task experiment involving both action and language phonological processing, and two independent experiments involving language phonology and action observation respectively. To control for differences in the visual processing and to enable a direct comparison between the tasks, the same visual stimuli were used for the mixed-tasks. Common neural areas for action observation and language phonology were located in the junction of the left inferior frontal/precentral gyrus, the left intraparietal sulcus and the left temporal-occipital cortex. Nevertheless, multi-voxel pattern analysis on the shared neural areas revealed that different patterns of neural activity were elicited for the action and language phonological tasks. Our results provide the first neuroimaging evidence that the common neural structures are engaged differently by action and language phonological processing.

1. Introduction

Recent studies on embodied cognition, language and action understanding have revealed close relationships between action and language including the existence of shared cortical areas for action and language tasks. Using functional MRI (fMRI), overlapping brain regions for action and language functions have been found in the inferior frontal gyrus, the parietal cortex and the temporal-occipital cortex (Baumgaertner et al., 2007; Hamzei et al., 2003; Meister and Iacoboni, 2007; Péran et al., 2010; Xu et al., 2009).

These common neural substrates suggest the existence of overlapping mental representations for action and language. It has been shown that verb generation and motor action tasks shared this common neural network (Hamzei et al., 2003; Péran et al., 2010). Other studies suggest that this common neural network processes “polymodal” action semantics: whether the action semantics are accessed from words or pictures (Baumgaertner et al., 2007), and whether from a vocal-auditory pathway or from a gestural-visual pathway (Xu et al., 2009).

However, activation within the same brain region reflected by fMRI does not guarantee the involvement of the same set of neurons (Peelen et al., 2006). An alternative possibility is that the shared brain regions are engaged by action and language with different activity patterns. Previous studies have shown that, on the mean activation level, the left inferior frontal and premotor regions are activated more strongly for language than for action, while the inferior parietal lobule is more engaged to action than to language (Andric et al., 2013; Hamzei et al., 2003; Péran et al., 2010), suggesting that the neural processes may be different for action and language within their shared brain regions. While the univariate analysis reveals to what degree a neural area is involved in a cognitive task, the multi-voxel pattern analysis (MVPA) takes a further step to uncover distinct activity patterns within an overlapping neural area and thus provides valuable means to get insights into cognitive representations and mental contents (Downing et al., 2007; Haxby et al., 2001; Haynes, 2015; Peelen et al., 2006). By employing MVPA and fMRI, Willems et al. (2009) has revealed that the neural activity within the premotor and primary motor areas dissociates between a lexical decision task and a motor imagery task involving the same action words. However, the MVPA method has not been used to analyse activity patterns for action and language within

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the inferior frontal, parietal or temporal-occipital regions, which is the focus of the present study. Previous studies have reported the neural overlapping for observing actions and comprehending action-related language (Andric et al., 2013; Baumgaertner et al., 2007; Hamzei et al., 2003; Péran et al., 2010), yet it is not known whether the language phonological network and the action-related neural network overlap with each other, and how their neural activity patterns are correlated. Given that we can distinguish multiple aspects of language (e.g., phonological processing, semantics and syntax), it becomes critical to examine which specific processes are common and which differ.

Previous research suggests that the posterior inferior frontal gyrus (pIFG) and the inferior parietal lobule (IPL) carry both action-related and language phonological processing. These two neural regions are suggested to hold "mirror neurons" that mediate action understanding by mapping the observed actions to the observer's own motor codes. Neural activity in the IPL has been associated with the representation of action goals irrespective of kinematic parameters (Hamilton and Grafton, 2006, 2008). As for language phonology, the pIFG activation reflects the demand for grapheme-to-phoneme conversion for alphabet languages (Fiebach et al., 2002; Heim et al., 2005) and the syllable-level orthography-to-phonology mapping for Chinse (Tan et al., 2005), while the IPL is implicated in phonological working memory (Tan et al., 2005; Vigneau et al., 2006). The shared neural areas for action observation and language phonology are predicted to be near the pIFG and the IPL, and the neural activity patterns within these regions are investigated in our present work.

The action and language phonological processing could be partly independent from each other within their shared neural substrates, which was assessed directly here by employing three fMRI experiments: language phonological discrimination (Experiment 1), action observation (Experiment 2), and both action observation and phonological discrimination (Experiment 3). A "mixed-task" design was employed for Experiment 3, in which the same visual stimuli (pictures of hand-object interactions) were involved for both a language phonological context and an action observation context, an idea adopted from Meister and Iacoboni (2007), in order to control for the visual processing and to ensure that any neural activity difference between the two tasks was attributed only to the task difference. The cortical regions activated by action observation and language phonology were identified and further divided into three sub-areas: neural areas shared by both action and language processing (action-language neurons, ALN), neural areas activated only for action processing (action neurons, AN) and those activated only for language processing (language neurons, LN).

We hypothesized that the neural activity patterns might differ between action and language phonology in their shared neural areas (ALN). This hypothesis was tested by two types of MVPA methods: pattern classification and pattern correlation. First, pattern classification (Misaki et al., 2010; Mur et al., 2009) was employed to assess whether the activity patterns were separable between the action and language tasks in the mixed-task experiment. High classification accuracies would imply that the neural processes in the ALN differ between action and language phonology. However, the pattern classification results alone could not reveal the nature of the difference or what the activity patterns reflected for each task. Pattern correlation analysis (Downing et al., 2007; Peelen et al., 2006) was carried out to further test whether the distinct activity patterns reflected phonology-specific and action-specific neural processes. To this end the activity patterns for the mixed tasks (Experiment 3) were correlated with those for the independent phonology (Experiment 1) and action (Experiment 2) tasks. If the different activity patterns reflected task-specific processing, we predicted that the mixed phonology task would correlate more with the independent phonology task than with the action task, and that the mixed action task would correlate more with the independent action task.

2. Material and methods

2.1. Participants

Eighteen normal participants (11 males and 7 females, mean age=22.94, age SD=3.55) were recruited from Tongji University, Shanghai, China. Participants were all native Chinese speakers, right-handed according to the Edinburgh Inventory (Oldfield, 1971), and had normal or corrected-to-normal visual acuity. The experimental procedure was approved by the ethics committee of Faculty of Medicine and Life Science Faculty, Tongji University. All participants signed informed consents and were paid for their participation. One individual was excluded from the fMRI analysis due to severe artefacts in the images. Some fMRI images were missing in the 4th run of another participant and the data from this run were also excluded. The remaining image data were used in the analysis.

2.2. Materials

For the language phonological judgment experiment (Experiment 1), we employed 48 pairs of Chinese characters with the same consonants and 48 pairs with different consonants (2.3°×2.3° in visual angle). Each pair of characters shared no visual similarity so that the consonant judgments were independent of orthographical features. For the size judgment task, we employed 48 pairs of Chinese characters of the same size and another 48 pairs of different sizes (2.3°×2.3° for the large stimuli, 1.7°×1.7° for the small stimuli), and none of them were used in the phonological judgment task. Each pair was presented vertically (Fig. 1). Character frequencies were all above 50 per million (Liu et al., 2007). The characters were matched for the word frequency and the number of strokes between the two tasks.

For the action observation experiment (Experiment 2), 12 objects were involved and pictures of hand actions were taken for each of them (8.2°×6.2°). The actions were performed with a right hand in a third-person perspective (Fig. 2a). Scrambled images were made from these action pictures with two levels of granularity (the grain size of 5×5 and 12×12 pixels respectively, Fig. 2b). To make the scrambled images, the action pictures were split up into small squares and the positions of the squares were shifted randomly.

For the mixed-task experiment (Experiment 3), 48 objects were used with 2 exemplars for each object (e.g., 2 different gloves). None of the objects were used in Experiment 2. Pictures of object-directed hand actions were taken for each object (96 pictures in total, 8.2°×6.2° in

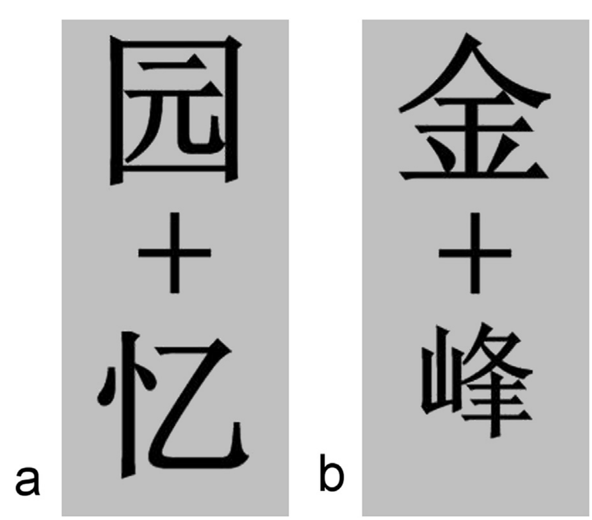

Fig. 1. Examples of the visual stimuli used in the phonological judgement task (a) and the size judgment task (b) in the language phonological experiment. In this example, 园(yuan) and 忆(yi) share the same consonant while the sizes for 金(jin) and 峰(feng) are different.