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Patterns of neural activity predict picture-naming performance of a patient with chronic aphasia

Yune Sang Lee[a,*], Jihad T. Zreik[b], Roy H. Hamilton[b,**]

[a] Department of Speech and Hearing Science, The Ohio State University, Columbus, OH, USA
[b] Department of Neurology, University of Pennsylvania, Philadelphia, PA, USA

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ABSTRACT

Naming objects represents a substantial challenge for patients with chronic aphasia. This could be in part because the reorganized compensatory language networks of persons with aphasia may be less stable than the intact language systems of healthy individuals. Here, we hypothesized that the degree of stability would be instantiated by spatially differential neural *patterns* rather than either increased or diminished *amplitudes* of neural activity within a putative compensatory language system. We recruited a chronic aphasic patient (KL; 66 year-old male) who exhibited a semantic deficit (e.g., often said “milk” for “cow” and “pillow” for “blanket”). Over the course of four behavioral sessions involving a naming task performed in a mock scanner, we identified visual objects that yielded an approximately 50% success rate. We then conducted two fMRI sessions in which the patient performed a naming task for multiple exemplars of those objects. Multivoxel pattern analysis (MVPA) searchlight revealed differential activity patterns associated with correct and incorrect trials throughout intact brain regions. The most robust and largest cluster was found in the right occipito-temporal cortex encompassing fusiform cortex, lateral occipital cortex (LOC), and middle occipital cortex, which may account for the patient's propensity for semantic naming errors. None of these areas were found by a conventional univariate analysis. By using an alternative approach, we extend current evidence for compensatory naming processes that operate through spatially differential patterns within the reorganized language system.

1. Introduction

Although some degree of language recovery occurs over time in many patients with chronic aphasia, object naming remains a challenging task for these individuals. One interesting observation of the naming deficits in patients with aphasia is that performance on particular items often fluctuates in an unpredictable and sometimes seemingly random manner; this manifests itself during picture-naming tasks as inconsistent name retrieval when the same pictures are repeatedly presented (e.g., ‘cat’ is named either ‘cat’ or other similar animals such as ‘dog’).

Various neuroimaging techniques have offered helpful insights for understanding the neuroanatomical basis of naming deficits in aphasia (Saur and Hartwigsen, 2012; Thompson and Ouden, 2008). For instance, voxel lesion symptom mapping (VLSM) is useful for identifying the distribution of lesions associated with different subtypes of aphasia (Bates et al., 2003; Schwartz et al., 2011). By contrast, functional magnetic resonance imaging (fMRI) allows for online measurement of neural activity in spared brain regions while patients with aphasia perform a particular language task such as overt picture naming (Fridriksson et al., 2009; Léger et al., 2002; Meinzer et al., 2013; van Oers et al., 2010; Postman-Caucheteux et al., 2009; Szaflarski et al., 2011). This approach has proven useful in highlighting changes in compensatory networks over the course of spontaneous language recovery (Saur et al., 2006).

However, standard fMRI analysis methods, which explicitly assume ‘greater’ or ‘less’ brain activation across different tasks or populations, are limited and often produce puzzling results in aphasia research. For example, Fridriksson and colleagues (2009) measured neural activity during a naming task in both chronic aphasics and normal subjects. Despite normal subjects clearly outperforming patients in the language task, no significant areas were found to differentiate healthy controls from aphasics with respect to neural activity in the language network. One potential explanation for this discrepancy is that successful retrieval of names may not depend on the intensity of activation but rather on the pattern of activation within the newly engaged language network. The central aim of the present fMRI study is to explore the compensatory neural processes that sustain language performance in

* Correspondence to: Goddard Laboratories, Room 518, University of Pennsylvania, 3710 Hamilton Walk, Philadelphia, PA, USA.
** Correspondence to: 104D Pressey Hall, The Ohio State University, 1070 Carmack Rd., Columbus, OH 43210, USA.
E-mail addresses: lee.7966@osu.edu (Y.S. Lee), roy.hamilton@uphs.upenn.edu (R.H. Hamilton).

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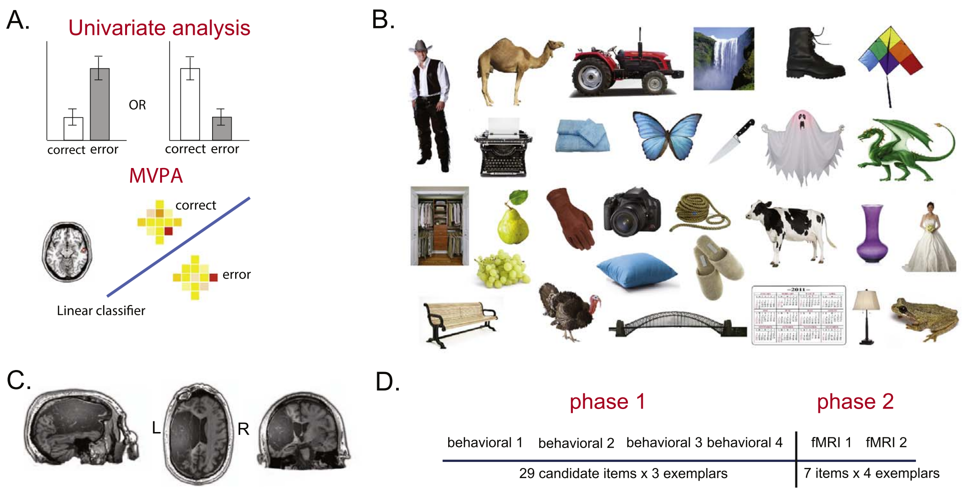

Fig. 1. A. Contrast of the rationale for conventional univariate analysis versus MVPA in linking neural activity to behavior. B. Some of the candidate pictures chosen from an existing PNT test-retest data set. These were presented during Phase 1 of behavioral sessions. C. Anatomical lesion profile of patient KL. An expansive lesion is shown in the left hemisphere encroaching the frontal, parietal, and temporal lobes.

aphasic patients by testing this hypothesis. To do this, we employed multivariate pattern-based analysis (MVPA), an alternative approach for relating neural activity to behavioral success or failure using machine-learning techniques (Mahmoudi et al., 2012). Fig. 1A depicts differences in the hypothesis between MVPA and the standard univariate analysis.

In this proof-of-concept study, we carefully selected a set of pictures that our subject could correctly name with 50% accuracy. These pictures would allow us to directly compare patterns of neural activity for correct versus incorrect trials, while holding constant a number of potential confounds, including visual object features and the complexity of object names (e.g., number of syllables). By adopting this strategy, we ensure that any differences observed in the MVPA are attributable to performance accuracy across trials. The participant underwent multiple behavioral sessions involving object naming in order to identify the candidate items for the main fMRI sessions. Consistent with our hypothesis, we found that MVPA could be used to link patterns of neural activity to behavioral outcomes but that standard fMRI analysis was insensitive to differences in performance.

2. Methods

2.1. Participants and stimuli

We identified candidate participants and stimuli for this study from an existing data set (Walker and Schwartz, 2012), in which 25 chronic aphasic patients performed the Philadelphia Naming Test (PNT) twice on different days. Seven candidate participants demonstrated naming scores that fell within the mid-range [39–70%, mean=53%] among the 25 potential subjects, and 29 picture items that were neither too difficult nor easy (Fig. 1B); these items yielded errors once in either of the two PNT sessions in 35–70% of the patient cohort.

Among the seven candidate participants, one patient (KL) volunteered for the present study. The patient's lesion profile is shown in the Fig. 1C. He was a 66-year-old right-handed man with chronic nonfluent aphasia who had a stroke encompassing the left hemisphere 11 years prior to the study and had previously participated in a transcranial magnetic stimulation (TMS) study in our laboratory (Hamilton et al., 2010). Written consent was obtained from the patient's spouse as approved by the Institutional Review Boards of the University of Pennsylvania and the Moss Rehabilitation Research Institute.

2.2. Experimental procedure

2.2.1. Phase 1: behavioral sessions

Prior to the main fMRI study, the participant completed four behavioral sessions comprised of overt picture-naming tests performed in a mock MRI scanner (Fig. 1D). Sessions were separated by a gap of two to four weeks. We employed 3 exemplars (e.g. 3 different pictures of a camel) for each of the 29 candidate items that were selected based on the PNT test-retest data. All images were in color and were matched for their size and luminance using Photoshop CS5 (Adobe Inc.). The typicality of the images was ensured by testing several colleagues at Penn's Center for Cognitive Neuroscience. A random sequence of the 87 (29 items x 3 exemplars) picture stimuli was determined by the De Bruijn sequence (Aguirre et al., 2011). The first half of the sequence (1st–44th trials) was presented in the first block, and the second half of the sequence (45th–87th trials) was presented in the second block. To match the number of trials across the block and not to break the random sequence, the last trial of the first block (44th) was repeated as the first trial of the 2nd block. This repetition was removed from the time-series prior to data analysis. Another random De Bruijn sequence was created and presented in the same manner, totaling 176 trials (44 trials×4 blocks) split across different blocks. During each block of the test, KL's verbal responses were recorded using a digital voice recorder attached to the inside of the mock MRI scanner; these recordings were later transcribed by the experimenter. Additionally, KL's head motion was recorded while he performed the picture-naming task.

2.2.2. Phase 2: fMRI sessions

Over the course of the 4 behavioral sessions, we identified seven candidate items that were suitable for the second phase of the study involving fMRI scanning: "butterfly," "boot," "camel," "closet," "cow," "pillow," and "turkey" The average accuracy for each of these pictures was approximately 50%. "Closet" was later replaced with "blanket" because the "closet" images contained multiple other namable objects (e.g., clothes). We chose "blanket" because this item was semantically related to "pillow." Furthermore, for each of the picture items, we included one additional exemplar (i.e., 4 exemplars per item) to decrease the repetition of images and to increase the visual variability of exemplars for each object. This resulted in a total of 28 stimuli for each run of the fMRI sessions, which were randomly presented using a slow event-related design (interstimulus interval=12 s). As was the case with the behavioral session, randomization was achieved based on a de Brujin cycle (Aguirre et al., 2011). There were a total of six functional EPI runs. KL's verbal response was monitored via a MRI-compatible