Introduction

Persons with aphasia who are trained to generate abstract words (e.g., justice) in a specific context-category (e.g., courthouse) have been shown to improve not only on the trained items, but also on concrete words (e.g., lawyer) in the same context-category (Kiran, Sandberg, & Abbott, 2009). However, the underlying neural mechanism of this generalization effect is unknown. Abstract and concrete words provide a unique opportunity to study specific neural activity related to direct training and generalization because they are thought to be processed differently by the brain (Binder, Desai, Graves, & Conant, 2009; Wang, Conder, Blitzer, & Shinkareva, 2010), but are linked in such a way as to promote generalization (Kiran et al., 2009). The current study examines the neural activation and functional connectivity patterns of abstract and concrete word processing in persons with aphasia before and after training abstract word retrieval to help uncover the neural mechanisms associated with direct training and generalization.

Methods

Subjects

Five persons with aphasia secondary to left hemisphere stroke (1 female, 4 males; mean age: 53) have completed the experiment. Five additional aphasic participants (2 females, 3 males; mean age: 65) are currently enrolled and are expected to complete the experiment shortly. All participants are right-handed native English speakers who are in the chronic phase of recovery. A battery of tests and questionnaires is conducted to determine language profile and to screen for MRI safety.

Treatment

All patients are trained on abstract word retrieval in a specific context-category (e.g., hospital, courthouse, etc.) by analyzing semantic features for each word within that context. The treatment paradigm is based on the Complexity Account of Treatment Efficacy (Thompson, Shapiro, Kiran, & Sobecks, 2003); abstract words are considered to be complex and thus expected to promote generalization to less complex, concrete words.

Stimuli. Each participant is trained on 10 abstract words from one of two context-categories (*hospital, courthouse*) that have been used in a previous study (Kiran et al., 2009). A third control category (*church*) is probed each week, but never trained. Ten concrete words from each context-category are considered targets for generalization. Words were chosen as abstract or concrete targets for a context-category based on word association norms (Kiss, Armstrong, Milroy, & Piper, 1973; Nelson, McEvoy, & Schreiber, 1998) as well as concreteness and imageability ratings (Gilhooly & Logie, 1980). The semantic features used during treatment consist of 15 general features derived from the dictionary definitions of concrete and abstract (e.g., exists only in the mind) and perceptual characteristics (e.g., can see it), and 15 additional features based on each patients' input about each word during the first treatment session. Fifteen distractor features (e.g., builds a nest) are also included.

Treatment procedure. Each patient is given up to 10 weeks of treatment in one context-category with the specific categories counterbalanced across participants. Generative naming is tested throughout baseline, treatment, and post-testing. Responses are divided into: target abstract words (e.g., emergency), target concrete words (e.g., doctor), other abstract words (e.g., anxiety), and other concrete words (e.g., needle). If 80% accuracy is reached on two generative naming probes in a row for target abstract words, treatment is discontinued. In each session the patient first sorts both abstract and concrete target words into their respective context-categories and then performs the following steps for each abstract word being trained: (1) select applicable semantic features from a predetermined set (see above), (2) answer yes/no questions about the semantic features of the word, (3) decide if the word is abstract or concrete, (4) supply a synonym for the word, and (5) recall the word being trained. At the end of each session, the clinician leads the patient in an untimed generative naming exercise for the trained context-category.

Functional Connectivity

All patients complete both a pre- and a post- treatment fMRI scan. Three patients also completed a control scan 10 weeks prior to the pre-treatment scan to measure any scan-to-scan changes unrelated to treatment. The fMRI task consisted of a word judgment paradigm in which patients explicitly labeled words as either abstract or concrete. As a control condition for this task, patients labeled letter strings as either vowels or consonants.

Data analysis. Functional MRI data are analyzed using a general linear model in the SPM8 software package. Task-related functional connectivity analyses are performed using the CONN toolbox for SPM8. Regions of interest (ROIs) for the functional connectivity analysis are created by constructing a 5 mm sphere around the peak activation voxels elicited during general word processing (i.e., abstract + concrete > control). These ROIs are constrained by areas shown to be involved in abstract and concrete word processing (Binder et al., 2009; Wang et al., 2010). Task-based semipartial ROI-ROI correlations are conducted individually for each patient, such that an “abstract network” and a “concrete network” are defined at each time point (i.e., pre- and post-treatment). Only positive correlations for which the confidence interval did not contain zero are included in the results.

Results

Treatment

All five patients who have completed treatment show improvement on the trained abstract words with effect sizes (ES) ranging from 5.82 to 17.53. Three of these patients also show generalization to concrete words in the same category with ES ranging from 1.73 to 5.36, while the remaining two patients did not show generalization with ES of -1 and -.79.

Functional Connectivity

All five patients showed changes in functional connectivity as a function of treatment; however, there appear to be subtle differences in the pattern of change depending upon whether or not the patient showed generalization in treatment.

Generalizers. All three patients who exhibited generalization from abstract to concrete words had similar overall numbers of connections before and after treatment, but showed treatment-induced changes in the quality of the connections. For example, all three patients increased the number of connections involving inferior frontal gyrus, angular gyrus/supramarginal gyrus, and middle frontal gyrus. Another notable change was a decrease in the ratio of left-seeded connections to right-seeded connections. In other words, the number of connections involving left-hemisphere regions (with all other connections taken into account) decreased after treatment, whereas connections involving the right-hemisphere regions (with all other connections taken into account) increased. This was true for both abstract and concrete networks.

Non-generalizers. Both patients who did not exhibit generalization showed a substantial increase in the overall number of connections, with P1 gaining nearly twice as many connections and P5 gaining over four times as many connections. Similar to the generalizers, the non-generalizers showed an increase in right-seeded connections compared with left-seeded connections, but importantly, this change only occurred for the abstract (trained) network.

Conclusion

All five patients show direct training effects when abstract words are trained. Three of these five also show generalization to concrete words in the same context-category. All five patients show changes in functional connectivity post-treatment. For example, all five patients show a decrease in the ratio of left-seeded connections to right-seeded connections for the abstract (trained) network. Importantly, generalizers also show this ratio change in the concrete (generalized) network. Furthermore, unlike generalizers, non-generalizers substantially increase connections in response to treatment. Overall, behavioral gains in treatment are measurable as specific neural changes in task-related functional connectivity in persons with aphasia.

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Figures

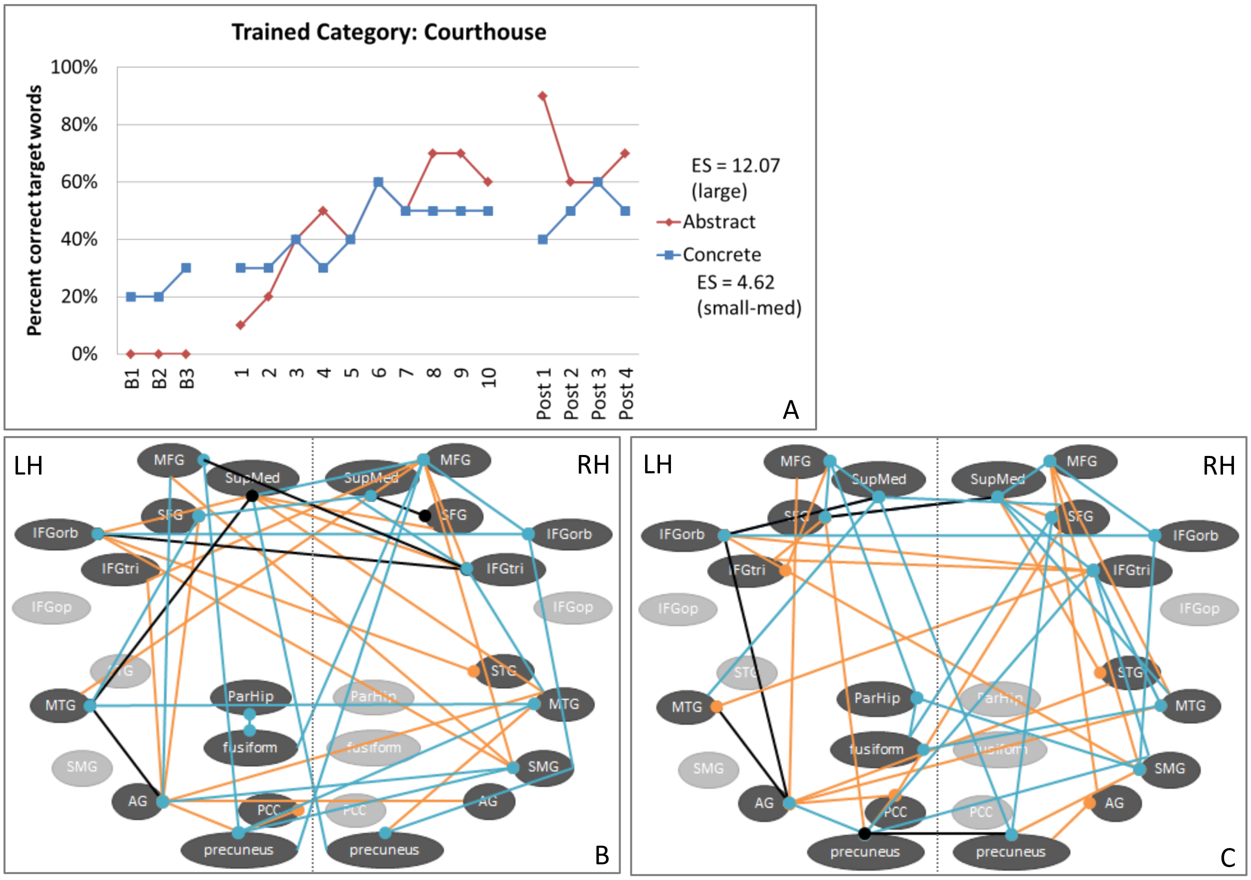

Figure 1. Example data from a patient who showed generalization in treatment. Panel A is a graph of the generative naming treatment probe results for the trained (abstract) and untrained (concrete) target words in the trained context-category. Panels B and C show the connections between regions of interest for the abstract and concrete word networks, respectively. Pre-treatment connections are represented in cyan, post-treatment connections are orange, and connections that remain the same represented in black. Note that there shift to bilateral IFG, MFG, and AG/SMG connections post-treatment for both networks.

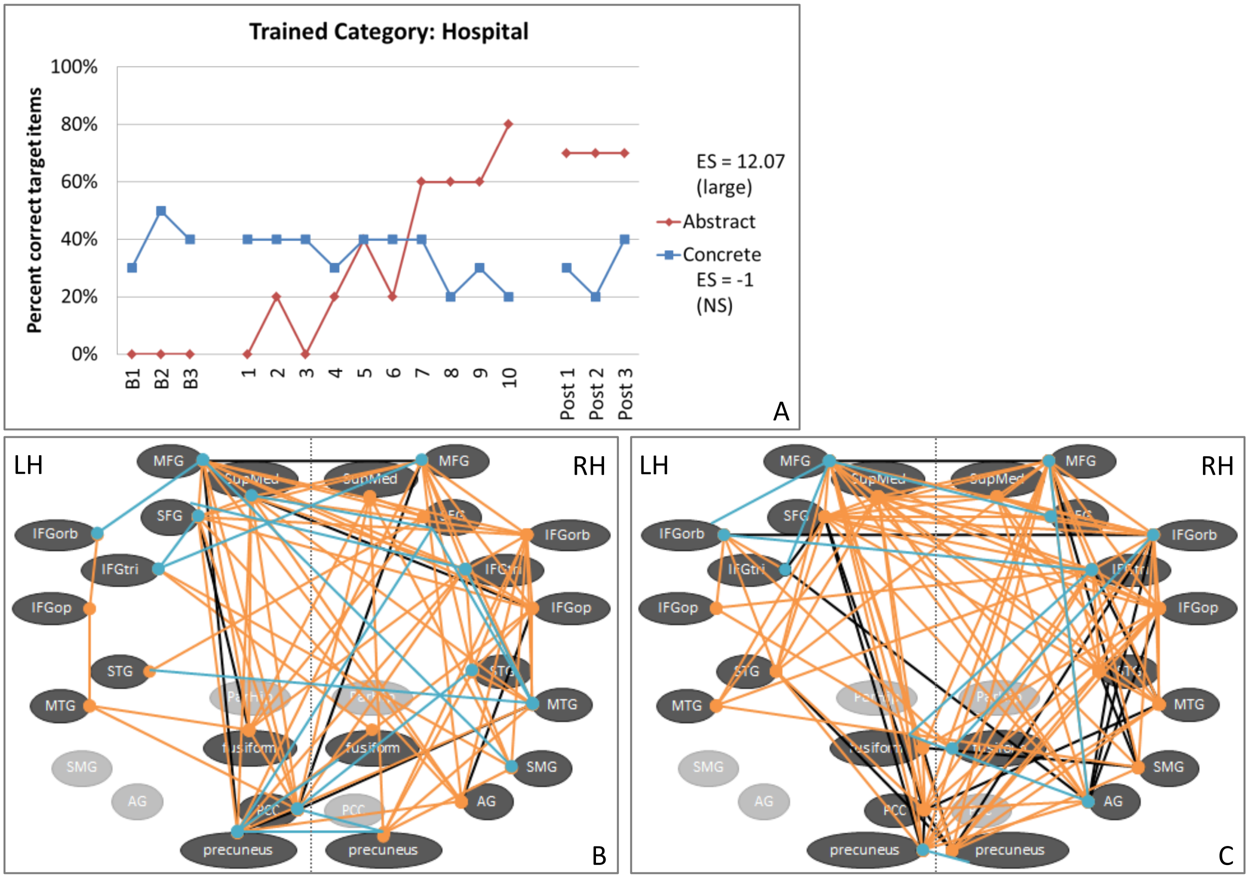

Figure 2. Example data from a patient who did not show generalization in treatment. Panel A is a graph of the generative naming treatment probe results for the trained (abstract) and untrained (concrete) target words in the trained context-category. Panels B and C show the connections between regions of interest for the abstract and concrete word networks, respectively. Pre-treatment connections are represented in cyan, post-treatment connections are orange, and connections that remain the same represented in black. Note that there is a substantial increase in connections for all regions, which is more pronounced for the concrete (untrained) network.