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Neural changes after phonological treatment for anomia: An fMRI study

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ABSTRACT

Functional magnetic resonance imaging (fMRI) was used to investigate the neural processing characteristics associated with word retrieval abilities after a phonologically-based treatment for anomia in two stroke patients with aphasia. Neural activity associated with a phonological and a semantic task was compared before and after treatment with fMRI. In addition to the two patients who received treatment, two patients with aphasia who did not receive treatment and 10 healthy controls were also scanned twice. In the two patients who received treatment, both of whose naming improved after treatment, results showed that activation patterns changed after treatment on the semantic task in areas that would have been expected (e.g., left hemisphere frontal and temporal areas). For one control patient, there were no significant changes in brain activation at the second scan; a second control patient showed changes in brain activation at the second scan, on the semantic task, however, these changes were not accompanied with improved performance in naming. In addition, there appeared to be bilateral, or even more right than left hemisphere brain areas activated in this patient than in the treated patients. The healthy control group showed no changes in activation at the second scan. These findings are discussed with reference to the literature on the neural underpinnings of recovery after treatment for anomia in aphasia.

1. Introduction

The use of neuroimaging techniques to study the neural underpinnings of recovery of language abilities following stroke has recently come to the forefront. As Pizzamiglio, Galati, and Committeri (2001) note in their review, many studies to date have focused on the neural processing characteristics associated with recovery from aphasia (i.e., in the absence of treatment). Evidence of both homologous right hemisphere (RH) adaptation and increased left hemisphere (LH) perilesional activity has been found (e.g., Calvert et al., 2000; Cherney & Small, 2006; Fernandez et al., 2004; Heiss, Kessler, Thiel, Ghaemi, & Karbe, 1999; Jodzio, Drumm, Nyka, Lass, & Gasecki, 2005; Rosen, 2000; Saur et al., 2006; Szekeres, Ylvisaker, & Cohen, 1987). The respective roles of the right and left hemispheres continue to be debated with regards to the question of the effects of neuroplasticity in recovery from aphasia, however Crosson et al. (2007) point out that the most fruitful approach to this question is not *whether* one or the other hemisphere plays a role in recovery, but rather, *when* and under what circumstances each hemisphere contributes to recovery.

An emerging area of enquiry is the investigation of the neural underpinnings of recovery following therapy for aphasia. Rijntjes and Weiller (2002) raise the important question of whether an observed cortical reorganization following treatment is responsible for a measurable behavioral change. Improved understanding at this level could potentially better inform theoretically motivated treatment approaches. The potential to identify therapy-induced areas of activation is encouraging based upon the studies conducted to

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date (e.g., Belin et al., 1996; Breier, Maher, Schmadeke, Hasan, & Papanicolaou, 2007; Cornelissen et al., 2003; Farias, Davis, & Harrington, 2006; Léger et al., 2002; Meinzer, Wienbruch, Djundja, Barthel, & Rockstroh, 2004; Musso et al., 1999; Pulvermüller, Hauk, Zohsel, Neininger, & Mohr, 2005; Richter, Miltner, & Straube, 2008; Small, Flores, & Noll, 1998; Wierenga et al., 2006). For example, Meinzer et al. (2004), using magnetoencephalography (MEG), found evidence for changes in perilesional activity, which was correlated with the amount of change in language functions after treatment in a large group of patients with chronic aphasia.

Recently, some studies have investigated neural activation patterns following treatment that was specifically aimed at improving anomia (i.e., word naming). For example, Léger et al. (2002) used functional magnetic resonance imaging (fMRI) to explore areas of activation for a picture naming task pre- and post-therapy in an individual with aphasia who had a naming deficit. They found that the pattern of activation post-therapy more closely mirrored that of healthy controls, with greater activation in the LH language areas surrounding the lesion and, in particular, in the left inferior frontal gyrus. Interestingly, they also found continued RH activation post-therapy, as well as activation of the left supra-marginal gyrus. They noted that the left supra-marginal gyrus is not typically associated with naming and suggested that it might represent a compensatory strategy induced by the therapy – specifically a greater attention to phonological features. A similar finding was found by Cornelissen et al. (2003) using MEG. They investigated the neural processing characteristics associated with a naming task in three individuals with a moderate anomia due to phonological output deficits pre- and post-therapy. For all three patients, naming improved post-therapy and was associated with greater activation in the left inferior parietal lobe. The authors attributed this to improved phonological encoding as a function of the therapy. Using time-resolved fMRI, Peck and colleagues demonstrated a homologous right hemisphere shift as a function of improved verbal response in one study (Peck et al., 2004), but not a subsequent one (Crosson et al., 2005). Davis, Harrington, and Baynes (2006) delivered an intensive semantic treatment to improve naming in one patient. The patient demonstrated improvements in both single word naming and noun production in connected speech after therapy, and fMRI showed increased activation of the left inferior frontal cortex and the right inferior posterior temporal cortex after therapy. Fridriksson and colleagues (Fridriksson, Morrow-Odom, Moser, Fridriksson, & Baylis, 2006; Fridriksson et al., 2007) have conducted two studies. In one (Fridriksson et al., 2006), three participants underwent three fMRI sessions both before and after therapy. In the two participants who benefited from the treatment, changes in perilesional activity in the left hemisphere as well as right hemisphere activation were noted. These included changes in the left temporal and the right posterior inferior parietal areas (Patient 1); and the frontal poles, the anterior cingulate gyrus and the left posterior supra-marginal gyrus (Patient 3). In a second study, Fridriksson et al. (2007) found increased activity bilaterally in the precuneus in two nonfluent patients who responded well to a combined semantic-phonological approach to naming treatment. Meinzer and colleagues (Meinzer, Obleser, Flaisch, Eulitz, & Rockstroh, 2007; Meinzer et al., 2006; Meinzer et al., 2008) have conducted both fMRI and MEG studies to investigate neuroplastic changes on naming abilities after Constraint-Induced Aphasia Therapy (CIAT). Meinzer et al. (2006) showed that correct word retrieval after treatment was associated with increased activation in the right inferior frontal gyrus (IFG) in one patient, but more bilaterally (in frontotemporal areas) in another patient (Meinzer et al., 2007). In their most recent study Meinzer et al. (2008) have used MEG in addition to fMRI to show that improved naming abilities in a group of eleven patients with chronic aphasia were correlated with increased activation within LH perilesional areas.

Based upon current theoretical models (e.g., Foygel & Dell, 2000), and as is evident from several of the studies reviewed above, of particular relevance to the study of naming difficulties in patients with aphasia are the domains of semantic and phonological processing. The results of recent investigations into these two domains in healthy participants have converged upon a consensus of brain areas involved. With regard to semantic processing, numerous studies undertaken with a variety of neuroimaging techniques (e.g., fMRI, MEG, positron emission tomography (PET)) and tasks (e.g., word fluency, category judgment) have consistently identified two particular areas of high importance – the left inferior frontal gyrus (LIFG), often the anterior portion, and the left middle temporal gyrus (Baxter et al., 2003; Binder et al., 1997; Calvert et al., 2000; McDermott, Petersen, Watson, & Ojemann, 2003; Perani et al., 2003; Roskies, Fiez, Balota, Raichle, & Petersen, 2001; Whatmough & Chertkow, 2002). With regard to phonological processing, the LIFG (often the posterior portion) has been identified as a critical area of activation (McDermott et al., 2003, Paulesu et al., 1997; Perani et al., 2003). In addition, activation of the left inferior parietal gyrus, including the supra-marginal gyrus, has been implicated in a number of phonological tasks including letter word fluency (Perani et al., 2003), rhyming (Kareken, Lowe, Chen, Lurito, & Mathews, 2000; Léger et al., 2002; Lurito, Kareken, Lowe, Chen, & Mathews, 2000) and naming (Cornelissen et al., 2003). Specifically in relation to picture naming, areas identified as being preferentially activated overlap with the above-mentioned areas for semantic and phonological processing. In healthy participants, picture naming has been shown to activate a large bilateral network (see Murtha, Chertkow, Beauregard, & Evans, 1999; Price, Devlin, Moore, Morton, & Laird, 2005).

In summary, studies that have investigated the neural underpinnings of recovery following naming therapy in particular, have generally found activation post-therapy in areas that have been linked to semantic and/or phonological processing in healthy participants, with the exception of Fridriksson et al. (2007) who also found post-treatment changes in areas not typically associated with language processing. In addition, some have reported increased LH compared to RH activation after therapy (Cornelissen et al., 2003; Meinzer et al., 2004; Meinzer et al., 2007); others have found increased RH activation after therapy (Meinzer et al., 2006; Peck et al., 2004); while still others have reported bilateral activation after therapy (Fridriksson et al., 2006; Léger et al., 2002; Meinzer et al., 2007). Patterns of activation have also been reported to be more similar to controls' after therapy in one study (Léger et al., 2002), but not similar to controls' in another (Fridriksson et al., 2007).

These studies are notable in their attempts to correlate therapy-induced improvements in naming performance with neural reorganization. They do, however, suffer from some methodological limitations. For instance, most studies do not include either a healthy control group tested at two time points or an untreated aphasic group, making it difficult to rule out potential test–retest effects (Carel et al., 2000) and effects of maturation (or time). In addition, with some notable exceptions (e.g., Cornelissen et al., 2003; Fridriksson et al., 2007; Léger et al., 2002), most treatment approaches were not specifically designed to treat word finding impairments, making it uncertain whether the activation findings reflect changes in word production per se or language processing more broadly.

In the current investigation we used fMRI to investigate the neural processing characteristics associated with word retrieval abilities after treatment for anomia. Incorporating appropriate control groups, we compared performance of individuals with aphasia on language tasks before and after a therapy program specifically targeted at increasing the awareness of the phonological aspects of words (Leonard, Rochon, & Laird, 2008). Participants from three