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Research report

Training verb argument structure production in agrammatic aphasia: Behavioral and neural recovery patterns

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ABSTRACT

Introduction: Neuroimaging and lesion studies indicate a left hemisphere network for verb and verb argument structure processing, involving both frontal and temporoparietal brain regions. Although their verb comprehension is generally unimpaired, it is well known that individuals with agrammatic aphasia often present with verb production deficits, characterized by an argument structure complexity hierarchy, indicating faulty access to argument structure representations for production and integration into syntactic contexts. Recovery of verb processing in agrammatism, however, has received little attention and no studies have examined the neural mechanisms associated with improved verb and argument structure processing. In the present study we trained agrammatic individuals on verbs with complex argument structure in sentence contexts and examined generalization to verbs with less complex argument structure. The neural substrates of improved verb production were examined using functional magnetic resonance imaging (fMRI).

Methods: Eight individuals with chronic agrammatic aphasia participated in the study (four experimental and four control participants). Production of three-argument verbs in active sentences was trained using a sentence generation task emphasizing the verb's argument structure and the thematic roles of sentential noun phrases. Before and after training, production of trained and untrained verbs was tested in naming and sentence production and fMRI scans were obtained, using an action naming task.

Results: Significant pre- to post-training improvement in trained and untrained (one- and two-argument) verbs was found for treated, but not control, participants, with between-group differences found for verb naming, production of verbs in sentences, and production of argument structure. fMRI activation derived from post-treatment compared to pre-

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treatment scans revealed upregulation in cortical regions implicated for verb and argument structure processing in healthy controls.

Conclusions: Training verb deficits emphasizing argument structure and thematic role mapping is effective for improving verb and sentence production and results in recruitment of neural networks engaged for verb and argument structure processing in healthy individuals.

1. Introduction

Individuals with agrammatic aphasia often present with verb production deficits. Notably, recent research indicates that verbs with greater (*vs* lesser) linguistic complexity are more difficult for these patients to produce. Verbs with more complex argument structure entries (i.e., a greater number of thematic roles and/or theta grids encoded within the verbs' representation) are more difficult compared to verbs with less complex entries. For example, ditransitive verbs like *deliver* and transitive verbs like *fix* are more difficult to produce than intransitive verbs like *laugh*. *Deliver* selects for three arguments: someone who delivers (i.e., an agent), something being delivered (i.e., the theme), and the receiver of the thing being delivered (i.e., the goal). In contrast, the verb *kick* only requires two arguments: an agent and a theme, and the verb *laugh* only requires one argument: an agent. This pattern (i.e., a verb argument structure complexity hierarchy) has been found in English, Dutch, German, Italian, and Russian agrammatic speakers (Bastiaanse and Jonkers, 1998; De Bleser and Kauschke, 2003; Dragoy and Bastiaanse, 2010; Kemmerer and Tranel, 2000; Kim and Thompson, 2000, 2004; Kiss, 2000; Luzzatti et al., 2002; Thompson et al., 1997), leading to the Argument Structure Complexity Hypothesis, stating that as the number of arguments increases for a verb, the more difficult it becomes to produce (Thompson, 2003).

In contrast to verb production deficits, individuals with agrammatic aphasia show retained ability to understand verbs in off-line auditory comprehension tasks (Kim and Thompson, 2000, 2004; but see Miceli et al., 1983) and show normal access to the subcategorization frames of verbs (i.e., encoded information pertaining to the syntactic environments in which the verb may appear) in on-line sentence processing tasks. That is, reaction times (RTs) are longer for verbs with multiple subcategorization options (e.g., the verb *send*) versus those with only one such option (e.g., the verb *fix*), as they are in healthy volunteers (Shapiro et al., 1993; Shapiro and Levine, 1990). Further, in a neuroimaging study using functional magnetic resonance imaging (fMRI) we (Thompson et al., 2010a) found normal activation patterns associated with argument structure complexity in four (of five) individuals with agrammatism, albeit some showed unilateral (right hemisphere – RH) activation because of necrosed tissue in relevant left hemisphere (LH) regions. Notably, patients with anomic aphasia typically present with greater difficulty producing nouns (objects) compared to verbs (actions), and in on-line sentence processing tasks, Wernicke's aphasic individuals do not show differential reactions times (RTs) to verbs based on linguistic complexity, indicating a lack of sensitivity to subcategorization information associated with verbs (Kim and Thompson, 2004; Shapiro et al., 1993; Shapiro and Levine, 1990). Given the convention that patients with agrammatic aphasia present with lesions in frontal regions and those with anomic aphasia present with temporoparietal lesions, these neurolinguistic studies point to unique roles for anterior and posterior portions of the LH in verb and verb argument structure processing.[1]

Neuroimaging studies examining verb processing in healthy individuals coincide with these general aphasic deficit patterns. Studies of verb (*vs* noun) processing using positron emission tomography (PET) and fMRI, as well as repetitive transcranial magnetic stimulation (rTMS) indicate left frontal convexity activation for verb processing and left temporal activation for nouns (e.g., Damasio and Tranel, 1993; Shapiro et al., 2005; Tyler et al., 2004), although inconsistent results across studies have been noted (see Crepaldi et al., 2011, for review). In addition, recent studies examining brain mechanisms involved in verb argument structure computation (i.e., processing of thematic roles encoded within the lexical representation of verbs) suggest that the posterior perisylvian region is also part of the network involved in verb processing. Using fMRI and a lexical decision task, Thompson et al. (2007) and Thompson et al., 2010a found that an increase in the number of arguments engenders increased activation in the angular and supramarginal gyri, bilaterally, in both young and older normal listeners. Ben-Shachar et al. (2003) found a similar pattern using a sentence processing task, with posterior superior temporal sulcus activation associated with increases in the number of arguments selected by verbs embedded in sentences. Further, in a verb production study, Den Ouden et al. (2009) found posterior activation associated with argument structure complexity (i.e., angular and supramarginal gyri, as well as bilateral fusiform, middle occipital, and superior parietal cortex). In addition, they identified activation for transitive compared to intransitive verbs in LH Broca's area – Brodmann areas (BAs) 44 and 45 – and surrounding areas. These findings suggest a LH network for verb processing, involving both frontal and temporoparietal regions.

Despite pervasive verb deficits in patients with agrammatic aphasia, few studies have addressed recovery of verb

[1] We recognize that many patients who present with behavioral deficits consistent with agrammatic or anomic aphasia do not show these clear-cut lesion patterns. For example, agrammatism may result from large lesions that include frontal as well as temporal and parietal regions (see Caplan et al., 1996; Vanier and Caplan, 1990; also see Wilson and Saygin, 2004).