Background and Rationale

Converging evidence from lesion, neuroimaging and other studies suggest that the neural network engaged for verbs differs from that of nouns. One crucial region of the network involves the inferior frontal cortex, i.e., patients with anterior brain damage and Broca's aphasia show greater verb, as compared to noun, production deficits (Luzzatti et al., 2002; Miceli et al., 1988); PET and fMRI studies have shown recruitment of anterior (Broca's and surrounding) areas for verbs as compared to nouns (e.g., Damasio & Tranel, 1993); rTMS studies have shown increased naming reaction times for verbs under frontal area stimulation conditions (Shapiro et al., 2001); and ERP studies have shown that verbs and nouns evoke unique frontal area topographies (Khader et al., 2003; Khader and Rösler, 2004). Other studies (both lesion and neuroimaging), however, have shown that posterior brain sites also play a role in verb processing (e.g., Berndt et al., 1996; Perani et al., 1999).

These mixed findings are likely related to a number of factors. Both lesion and neuroimaging studies have varied greatly in technical detail as well as in the psycholinguistic tasks and parameters related to the stimuli, e.g., word length, frequency, familiarity and imageability often are not controlled (Tyler et al., 2001). In addition, most studies have not controlled verbs for their argument structure properties, which are known to influence both verb production and processing; i.e., verbs with greater argument structure complexity engender greater processing resources and are more difficult for agrammatic aphasic patients to produce, as compared to verbs with simpler argument structure entries (Kim & Thompson, 2004; Thompson, 2003; Shapiro et al., 1993). Further, there is evidence suggesting that posterior brain mechanisms are crucial for argument structure processing; i.e., Wernicke's aphasic patients do not show on-line sensitivity to argument structure complexity, as do Broca's patients (Shapiro & Levine, 1990), and a recent study fMRI study showed increased bilateral temporal area activation as a function of verb argument structure complexity (Ben Zachar et al., 2003).

This study examined the neural correlates of verbs, controlled for their argument structure properties, and nouns by semantic class (animals and tools) using an event related (ER) fMRI design.

Method

Participants: Participants included nine normal volunteers and seven individuals with agrammatic, Broca's aphasia. All were monolingual right-handed English speakers, well-educated, and demonstrated good hearing and visual acuity. The aphasic participants were mild to moderately impaired, as assessed by the Western Aphasia Battery (Kertesz, 1982), with Aphasia Quotients (AQs) ranging from 62-84; they were between 1 and 14 years post-onset and between 35 and 78 years of age at the time of testing. All showed asyntactic comprehension patterns and agrammatic, nonfluent production.

Stimuli: A set of 90 one-, two- and three-argument verbs (30 each), 60 nouns (30 animals, 30 tools), and 50 pseudowords were selected. Stimuli from both word classes were carefully controlled for frequency of occurrence, familiarity, imageability and word length. Verbs were selected for their argument structure status using the Brandeis Verb Lexicon (Grimshaw & Jackendoff, 1983). In addition, eight neurolinguists ranked each verb by type with high reliability.

Design: Stimuli were divided into two runs. Each run included 125 target stimuli presented in a pseudorandomized sequence with null events comprising 40% (time) of each run. Superlab was used for visual presentation of the stimuli. Each stimulus was presented for 1200 ms followed by a 500 ms blank screen. A lexical decision task was used with subjects responding by button press.

Procedure: Both anatomical and functional scans were obtained using a 3T Trio Siemens scanner. T1-weighted 3D volumes were acquired using MP-RAGE; T2-weighted images were obtained with echoplanar imaging.

Data Analysis: The data were analyzed using SPM2 running in a Matlab environment. Functional scans were corrected for slice-acquisition timing and realigned; anatomical volumes were coregistered to the mean image, and normalized to the MNI 152 template brain. The functional volumes were then normalized and were smoothed with a 10mm isotropic Gaussian kernel. Resulting stereotactic coordinates, in MNI-space, were then transformed into Talairach space. FMRI data derived for each condition were analyzed with regard to main effects and subsequent differential comparisons were made. All analyses used a significance level of $p < .001$ (uncorrected), with a 3-voxel extent threshold.

Results and discussion[1]

The fMRI data were first analyzed by comparing activation under verb, as compared to noun, conditions. Significant activation was seen in the left and right inferior frontal and superior temporal areas as well as the posterior-superior parietal

[1] Only the data from our normal participants are presented here as the aphasic data are currently being analyzed. Data from both subject groups will be presented and discussed at the meeting.

region and other areas (see Figure 1). In contrast to verbs, nouns elicited more widespread, and little perisylvian, activation (Figure 2).

Examination of activation patterns for 3-argument versus 1- and 2- argument verbs revealed bilateral Wernicke's area recruitment (see Figure 3). A follow-up region of interest (ROI) analysis further showed that, while Broca's area was active for processing all verbs, when one-place verbs were compared to two- and three-place verbs, no Wernicke's area activation was found in either hemisphere. In contrast, when two-place verbs were compared to one-place verbs, left Wernicke's area was active, and when three-place verbs were compared to one-place, two-place, and one- and two-place verbs, Wernicke's area was active bilaterally (see Table 1).

These findings are consistent with other data indicating that both anterior and posterior portions of the language network are crucial for verb processing (Perani et al., 1999; Grossman et al., 2002). Broca's area activation may reflect the crucial role of this region in syntactic processing – i.e., verbs are highly tied to the syntax, selected from the lexicon together with their argument structure properties which are crucial for triggering automatic phrase structure building processes. Our argument structure effects suggest, however, that Wernicke's area is critical for computing the argument structure properties of verbs. This interpretation is in line with the neuroimaging data derived by Ben Zachar et al. (2003) as well as data showing that Wernicke's aphasic patients fail to process argument structure normally (McCann & Edwards, 2000; Shapiro & Levine, 1990).

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Table 1. Region of interest (ROI) data. Cluster size (in voxels).

Contrast	Left Wernicke's Area		Right Wernicke's Area	
	Coordinates	Cluster Size	Coordinates	Cluster Size
1pv vs. 2pv	--		--	
1pv vs. 3pv	--		--	
1pv vs. 2pv + 3pv	--		--	
2pv vs. 1pv	(-60, -57, 6)	18		
2pv vs. 3pv	(-60, -60, 6)	7		
3pv vs. 1pv	(-57, -54, 6)	24	(60, -33, 15)	29
3pv vs. 2pv	(-54, -51, 9)	17	(60, -33, 15)	29
3pv vs. 1pv + 2pv	(-54, -51, 9)	15	(60, -33, 15)	29

Note: 1pv=one-place verb; 2pv=two-place verb; 3pv=three-place verb.

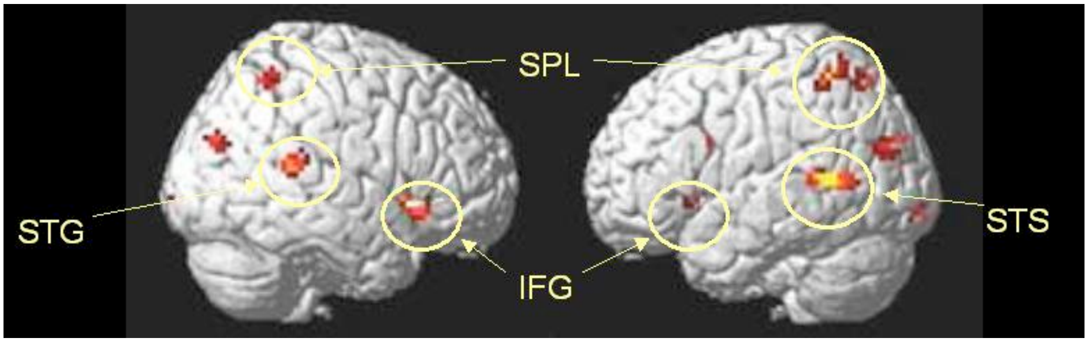

Figure 1. Lateral images showing activation for under verb, as compared to noun, conditions. Significant activation was seen in the left and right inferior frontal and superior temporal areas. Additional activation was evident bilaterally in the posterior-superior regions of the parietal lobe, and the visual association cortex, cuneus and precuneus. Activations were significant at $p < .001$ (uncorrected) at a 3-voxel extent threshold.

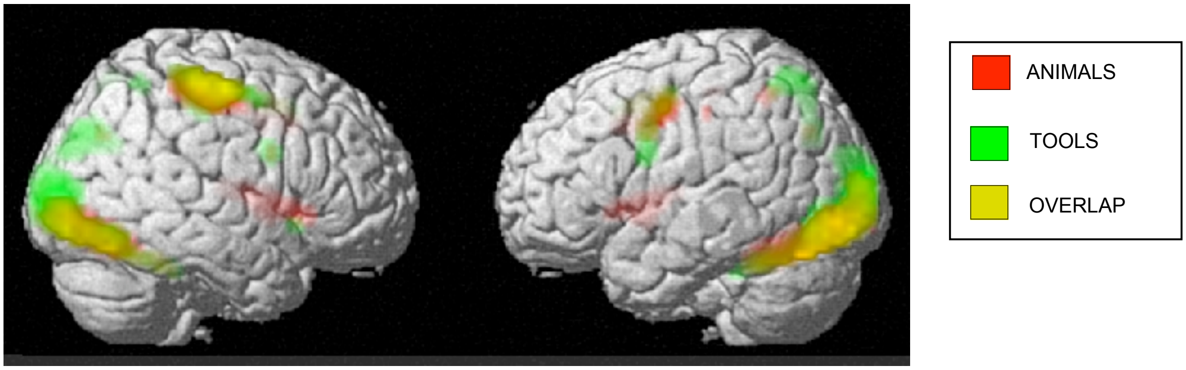

Figure 2. Lateral images showing activation under noun conditions. Activation was observed in the middle frontal and precentral gyri, anterior cingulate gyrus, insula and the basal ganglia. Posteriorly, significant activation was noted in the postcentral gyrus, the superior parietal lobule, visual association cortices, and the fusiform gyrus. Bilateral activation of all areas was noted with the exception of the insula, basal ganglia, and post central gyrus (left hemisphere only). Activations were significant at $p < .001$ (uncorrected) at a 3-voxel extent threshold.

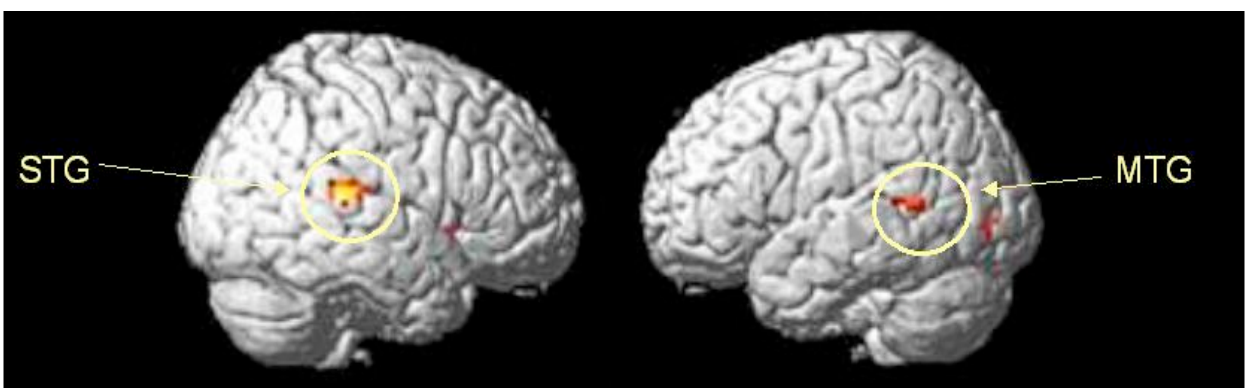

Figure 3. Regions of statistically significant activation under 3-argument as compared to 1- and 2-argument verb conditions. Activations were significant at $p < .001$ (uncorrected) at a 3-voxel extent threshold.