Cortical and structural connectivity damage correlated with impaired syntactic processing

Introduction

Problems with sentence processing and production are not exclusive to speakers with agrammatic aphasia. Besides peripheral problems with auditory processing or articulatory control, lexical retrieval, attention and short-term memory deficits may all underlie difficulties with organizing words into sentences, applying inflectional morphology and correctly accessing and processing verb argument structure. Lesions that result in sentence processing problems are therefore not homogeneously limited to a small region. However, sentence processing and production can be broken up into components, in order to investigate the brain-behavior relationship in greater detail. The Northwestern Assessment of Verbs and Sentences (NAVS) allows for such investigations, as it consists of several tasks that tap into different components of syntactic processing (Cho-Reyes & Thompson, 2012). In particular, the NAVS focuses on the pivotal role of verbs and verb argument structure in sentence (de)construction.

With respect to structural syntactic features that affect sentence processing, it is of interest to investigate deficits that are characterized by greater problems with noncanonical sentence structures, compared to canonical structures. Patients with such a pattern of impairment may be considered to have a specific deficit in complex syntactic processing. Brain-behavior investigations that focus on such patterns may yield greater insight into regions and/or networks that serve a particular role in the syntactic computations that underlie the relation between canonical and noncanonical sentences (Magnusdottir et al., 2013).

As part of a larger study into correlations between brain damage and functional deficits, we submitted participants to an MRI scanning protocol that included anatomical scans, diffusion tensor imaging, resting state functional imaging, and perfusion imaging. Such a combination of methods reduces the chance of underestimating the extent of stroke-induced brain damage and its effect on patient symptoms. We investigated correlations with performance on NAVS subtests, as well as with the ratio of performance on canonical versus noncanonical sentence structures.

Methods

Thirty-one right-handed participants had suffered a single left-hemisphere stroke, not always resulting in aphasia (mean WAB AQ 74; range 25.3-99.6). Imaging was performed with a Siemens 3T Tim Trio scanner, using the following protocols: (1) 3D T1-MRI; (2) high-resolution T2-MRI; (3) resting state fMRI (REST); (4) diffusion tensor imaging (DTI); and (5) perfusion imaging (CBF). Perfusion data are still being analyzed, so these results are not included here.

The following NAVS subtests were administered: (1) the Argument Structure Production Task (ASPT), in which participants produce a sentence based on an action picture that includes the names of the verb and its argument(s); (2) the Sentence Priming Production Task (SSPT), in which participants are prompted with an example sentence to produce a sentence of the same construction (active, passive, object cleft, subject cleft, etc.); and (3) the Sentence Comprehension Task (SCT), a sentence-picture matching task. In addition to the regular scores yielded on these subtests, we scored two derived measures. First, we calculated error rates on ‘attempted’ trials for the SSPT. Some patients experience difficulty maintaining task understanding, which lowers their scores, though not necessarily due to sentence production problems. In our SSPT_att measure, we only included trials that had a relevant attempted non-zero response. Second, we added an ASPT_G score, reflecting whether a response was fully grammatical. The standard ASPT_A score does not reflect this, as it allows for a ‘correct’ score in cases where participants produce the verb and all arguments in the correct order, without determiners or verb inflection. Furthermore, for the SSPT and SCT subtests, we calculated the ratio of errors on noncanonical structures relative to those on canonical structures (NC). On a 0-1 scale, a score below 0.5 indicated greater problems with noncanonical sentences and a score above 0.5 indicated greater problems with canonical structures. We also computed a summary score over these ratios (NC_comb), to reflect problems with noncanonical structures across tasks.

Based on the anatomical scans, lesion maps were drawn for each participant. Analyses of brain-behavior correlations were conducted over Brodmann's areas, with the exception of the DTI analyses, which were performed on tracts identified in the Johns Hopkins University white matter atlas. All analyses were corrected for multiple comparisons through permutation testing (2000 permutations). Analyses were one-tailed (we predict injured tissue will only cause poorer performance), with alpha=.05.

Results

Scores on the NAVS subtests were highly correlated with one another, as well as with WAB-AQ (r^2=0.49-0.94; p<.05). The NC scores (mean 0.44; range 0-.06) were not correlated with these, nor with WAB-AQ, but only with one another (r^2=0.12-0.92; p<.05).

Brain regions and fiber tracts in which damage correlated with poor performance are shown in Table 1. None of the imaging measures revealed regional correlations with specifically poor performance on noncanonical sentence structures.

Discussion and Conclusion

The behavioral scores show that it is not the case that all patients with sentence processing or production problems have greater difficulty with noncanonical structures. In contrast to Magnusdottir et al. (2013), we did not find correlations between localized brain damage and poor performance on noncanonical sentences. That study included 50 participants, while we included 31 in the present analysis (the study is ongoing), so one possibility is that our power is relatively low. Alternatively, the current results may indicate that the network of regions that underlie complex syntactic processing is too diffuse for a focally localized lesion to survive the threshold as singularly responsible for noncanonical sentence computation. Inclusion of more participants should shed light on this matter, which speaks directly to the neural correlates of complex syntactic processing.

Correlations between lesioned tissue and the NAVS production subscores, as well as between those scores and resting-state activity, largely confirm results from Lukic et al. (2013), who also investigated lesion-deficit correlations based on the NAVS, but with an ROI-based approach. Damage to superior temporal gyrus is highly predictive of sentence processing and production problems and the current study adds damage to middle temporal gyrus, angular gyrus and temporal pole, among others, as predictors of problems on the production tasks. Contrary to Lukic et al. (2013), we do not find Broca's area to be involved in SPPT performance, but we do find damage to this area to be predictive of low scores on our ASPT_G measure, reflecting participants' ability to produce grammatical responses.

Finally, the DTI data are an interesting addition to work on lesion-symptom mapping in the domain of sentence processing. We find that fiber tracts connecting LH IFG and SFG to areas that may be part of an attention network (cuneus and anterior cingulate) importantly subserve sentence processing. Also, our data show that left-hemisphere lesions may affect contralateral structural connectivity, in turn predictive of sentence processing problems.

References

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Table 1 *Significant brain-behavior correlations*

Behavioral measure	**Lesion (binary) LH Brodmann**	**REST LH Brodmann**	**DTI**
ASPT_A	34, 38, 48	21, 22, 43, 48	*ns*
ASPT_G	21, 22, 38, 41, 42, 43, 44, 47, 48	22, 48	LH IFG_tri* – LH Precentral Gyr. LH IFG_tri **--** LH Cuneus LH IFG_orb – LH Fusiform Gyr. LH IFG_orb – LH Cuneus LH SFG (post) – LH dorsal AC
SSPT_total	21, 22, 38, 39, 41, 42, 48	22	LH IFG_orb – LH Cuneus LH SFG (post) – LH dorsal AC
SSPT_att	21, 22, 38, 41, 42, 48	22	LH IFG_tri – LH MTG pole LH IFG_orb – LH Cuneus LH SFG (post) – LH dorsal AC
SCT	21, 22, 41, 42, 48	22	LH SFG (post) – LH dorsal AC. RH SFG (post) – LH Cuneus RH IFG_orb – RH MOG
SSPT_tot_NC	*ns*	*ns*	*ns*
SSPT_att_NC	*ns*	*ns*	*ns*
SCT_NC	*ns*	*ns*	*ns*
NC_combined	*ns*	*ns*	*ns*

*Anatomical abbrev.: IFG = inferior frontal gyrus; tri = triangular part; orb = orbital part; Gyr = gyrus; SFG = superior frontal gyrus; AC = anterior cingulate gyrus; MTG = middle temporal gyrus; MOG = middle occipital gyrus.