We hypothesized that in acute stroke, some patients show structure-specific, task-independent deficits in sentence comprehension, with chance level of accuracy on passive reversible sentences, more impaired comprehension of object-cleft than subject-cleft sentences, and more impaired comprehension of reversible than irreversible sentences in both sentence-picture matching and enactment tasks, but that this pattern of "asyntactic comprehension" is associated with impaired working memory rather than dysfunctional tissue in Broca's area as previously proposed. We found that the pattern did exist, but was often independent of both impaired working memory and ischemia in Broca's area (which were less often independent of one another).

Asyntactic Comprehension, Working Memory, and Acute Ischemia in Broca's Area

It is widely agreed that patients with Broca's aphasia or damage to Broca's area often have impaired syntactic processing (Caplan, 1987). Functional imaging studies also show activation of Broca's area during syntax processing (Just et al. 1996), although these studies also show activation in other areas (Caplan 2002). However, the type of deficit in syntactic comprehension observed in these patients is widely debated. Grodzinsky (2000) has made the strong claim that Broca's area is the "neural home to mechanisms involved in the computation of transformational relations between moved phrasal constituents and their extraction sites." On the basis of the "trace deletion hypothesis" (TDH), according to which Broca's aphasic patients do not maintain traces of movement in sentence constructions derived by transformational movement, such as

verbal passive and object relative clause constructions, he predicts chance or below chance performance comprehension of these sentences in all patients with lesions of Broca's area (but see Berndt et al., 1996; Hickok & Avrutin 1995; Caplan et al. 1996). The influence of verbal working memory (VWM) deficits on sentence comprehension has also been controversial. Some investigators have viewed VWM as a single resource that supports a variety of language processes (Just & Carpenter, 1992). Others view VWM as a set of resources that each support different language comprehension functions (Caplan & Waters, 1999). Functional imaging studies show that VWM tasks and comprehension of movement-derived sentences are both associated with activation in Broca's area, and many studies have found an association between VWM and sentence comprehension (Vallar & Baddeley, 1984).These associations might be observed because the 2 tasks both initially depend on Broca's area. It is important to determine if there are deficits specific to particular tasks or sentence structures to distinguish general deficits in processing semantically reversible sentences (e.g. due to impaired working memory) from specific syntactic deficits (e.g. trace deletion). Caplan, Dede, and Michaud (2006) studied patients with chronic stroke and found none with structure-specific, task-independent deficits. However, the failure to find such patients in the chronic stage could be due to differential practice of one task in language therapy. Therefore, we studied patients with acute stroke, which also allowed us to examine the relationship between asyntactic comprehension, working memory, and acute tissue dysfunction in Broca's area, before the opportunity for reorganization of structure-function relationships. We tested the following hypotheses:

1. In acute stroke, some patients show structure-specific, task-independent deficits in sentence comprehension, with chance (or below) level of accuracy on passive reversible sentences, more impaired comprehension of object-cleft than subject-cleft sentences, and more impaired

comprehension of reversible compared to irreversible sentences in both sentence-picture matching and enactment tasks (a pattern we call "asyntactic comprehension"); 2. In acute stroke, asyntactic comprehension is associated with impaired working memory, but not with dysfunctional tissue (infarct and/or hypoperfusion) in Broca's area (BA 44/45).

Methods

Western Aphasia Battery-Revised was administered for purposes of aphasia classification. Classification was based on published criteria, by the tester and another judge. Additional tests included:

Sentence Picture Matching (SPM): Participants see two pictures on a computer screen and simultaneously hear and see a written sentence underneath the picture. The participant has to press a key to indicate which picture matches the sentence they hear and see. There are a total of 80 experimental trials. There are 20 sentences of each category; passive, active, object-cleft and subject-cleft. Within these categories each contains 10 reversible sentences and 10 irreversible sentences.

Enactment Participants hear and see a sentence on the computer screen and are asked to act out the sentence using laminated paper figures/dolls. The figures/dolls represent the subjects and objects in each sentence. The number of trials and sentence categories are the same as the SPM task.

Working Memory was tested with forward and backward digit span, 2 trials at each span length, giving credit for the maximum span length for which the patient was successful on at least one trial.

Magnetic Resonance Imaging was analyzed for dysfunction in Broca's area on Diffusion (DWI) and perfusion (PWI) weighted imaging by the senior author without knowledge of results of the language assessment. For the purpose of this paper, each MRI was registered to the MNI atlas, and we determined whether each patient's infarct and/or area of hypoperfusion covered part or all of the area corresponding to cytoarchitectural areas 44 and 45 in the probabilitistic map of Broca's area based on an autopsy study (Amunts, et al. 1999).

Statistical Analysis

We first identified the pattern of asyntactic comprehension as a dichotomous variable (present or absent). The presence of asyntactic comprehension required: performance that was not significantly above chance level of accuracy on passive reversible sentences; $\geq$ 10 percentage points lower accuracy on object-cleft than subject-cleft sentences, and $\geq$ 10 percentage points lower accuracy on reversible compared to irreversible sentences. We identified associations between ischemia (hypoperfusion/infarct in all or part of Broca's area and (1) this pattern of asyntactic comprehension and (2) impaired VWM. We then compared patients with and without asyntactic comprehension on a variety of language tests using ANOVA.

Results

Results are summarized in Tables 2 and 3.

A total of 14 patients showed asyntactic comprehension on at least one test, and 16 patients did not show this pattern of performance. Of the 14 patients with asyntactic comprehension, 6 patients showed this pattern on both sentence-picture matching and enactment, 6 patients showed

the pattern only on one test (3 in spm and 3 in enactment), and 2 failed to complete one or more tests.

Discussion

We confirmed our first hypothesis, that in patients with acute stroke, some patients show structure-specific, task-independent deficits in sentence comprehension, with particular impairment of movement-derived sentences. This difference between acute and chronic stroke might reflect differential practice in particular types of tasks after stroke, that reduces the task demands for that task, and allows better performance on passive sentences, reversible sentences, and those with object-cleft clauses in the practiced task but not in unpracticed tasks. Nevertheless, some patients showed asyntactic comprehension in just one task – either enactment or spm, which could be due to random variability in performance or an interaction between the task demands and sentence structures that is not consistent across patients.

We failed to find a consistent relationship between measures of working memory (forward and backward digit span) and asyntactic comprehension. There was a correlation between backward span and object-cleft sentences only in patients with asyntactic comprehension. However, some patients with normal forward and backward digit span showed asyntactic comprehension. Therefore, asyntactic comprehension cannot be attributed to impaired working memory in many cases. The correlation between digit span and comprehension of syntactically complex sentences cannot be due to both asyntactic comprehension and impaired working memory being associated with damage to Broca's area, because only impaired working memory was associated with damage to Broca's area. To our surprise, there was no association between asyntactic comprehension and acute dysfunction in Broca's area.

In summary, there may be distinct causes of the pattern of sentence comprehension impairment that we and others have referred to as "asyntactic comprehension." One cause may be limited working memory, but this seems to be uncommon in acute stroke (most of whom have relatively small strokes).

Table 1. Exclusion Criteria for Participants

Acute stroke limited to the brainstem or cerebellum
Prior symptomatic stroke or neurological disease
Diminished level of consciousness or requiring intubation
Ongoing, intravenous sedation
Presence of any ferromagnetic implant (cardiac pacemakers, aneurysm clip)
Other contraindication to MRI
Pregnancy
Allergy to Gadolinium contrast or renal failure (estimated glomerular filtration rate <60)
Severe claustrophobia
Known history of functionally significant uncorrected hearing loss
Known history of functionally significant uncorrected visual loss

Table 2: Associations Between Deficits or Between Lesion and Deficit

Associations Between Deficits	Chi Square	P value	Fisher exact P value
Asyntactic comprehension on ≥ 1 test and Impaired working memory defined as backward digit span ≤2	1.98	0.159	ns
Asyntactic comprehension on ≥ 1 test and Impaired working memory defined as forward digit span ≤ 4	4.4	0.035	0.056 (trend)
Associations Between Lesion and Deficit			
Dysfunctional Tissue in Broca's area And asyntactic comprehension on ≥ 1 test	0.075	0.93	ns
Dysfunctional tissue in Broca's area and Impaired working memory, defined by backward digit span ≤2	6.7	.0009	0.029
Dysfunctional tissue in Broca's area and Impaired working memory defined by forward digit span ≤ 4	0.24	0.62	ns

Table 3. Mean Percent Correct Performance Across Patient Groups (by ANOVA)

Test	Patients with Asyntactic Comprehension	Patients without Asyntactic Comprehension	F	P value
Sentence picture matching				
Passive sentences	74	94	9.9	0.004
Object-cleft sentences	80	95	8.7	0.007
Reversible sentences	79	93	9.9	0.004
Enactment				
Passive sentences	74	97	6.8	0.022
Object-cleft	74	94	6.7	0.023
Reversible sentences	83	95	4.3	0.060
Digits forward	5.0	7.1	5.0	0.036

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