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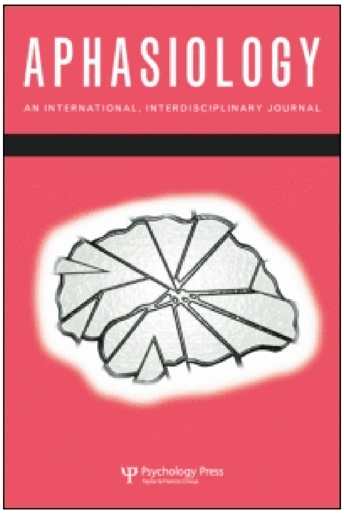

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Testing the limits of language production in long-term survivors of major stroke: A psycholinguistic and anatomic study

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Testing the limits of language production in long-term survivors of major stroke: A psycholinguistic and anatomic study

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Background: There is still a dearth of information about grammatical aspects of language production in aphasia.

Aims: Making novel use of methods of *elicited production* aimed at testing the limits of competence, we studied three cases of chronic aphasia, stemming from major stroke. We asked: (1) Whether the elicited production method reveals sparing of language abilities not readily evidenced in spontaneous utterances or on conventional aphasia tests. (2) Which language production abilities survive damage to both Broca's region and Wernicke's region?

Materials & Procedures: Targeted words, morphological and syntactic structures were elicited by sentence completion with supporting linguistic and visual context. Targets

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were never modelled during the procedure. For verbs, visual and auditory contexts emphasise completed actions, targeting past tense forms. Lesion description was based on structural MRI scans.

Outcomes & Results: The three participants showed partially spared ability to produce nouns, adjectives, and verb stems in context. The elicitation method proved more productive in some cases than picture prompts or sentence prompts. Past tense inflections were usually omitted. Hence stems and inflections were dissociable. Two participants showed partial success with the passive, and no participant produced a full relative clause, including the relative pronoun, but two produced reduced forms of subject relatives. Partial sparing of production capability in these cases points to the likely importance of portions of the left hemisphere remote from Broca and Wernicke regions.

Conclusions: This application of elicited production methodology demonstrates possibilities of lexical, morphological, and syntactic production not evident in spontaneous utterances or by conventional aphasia tests. Some lexical and grammatical capabilities survived massive damage to both anterior and posterior portions of the left hemisphere.

Keywords: Aphasia; Grammatical production; Recovery of production.

Conclusions about sparing and loss after cerebral damage depend crucially on the method of assessment. Conventional clinical tests for assessment, although they have brought about important advances to the field of aphasia study and rehabilitation, provide little detail about specific kinds of linguistic structures (Bastiaanse, Edwards, Maas, & Rispens, 2003). For example, the Boston Diagnostic Aphasia Examination (BDAE; Goodglass & Kaplan, 1983; Goodglass, Kaplan & Barresi, 2001) focuses more on word retrieval in isolation than in sentence context and more on nouns than on verbs or grammatical words. Spontaneous speech samples and sentence repetition are the primary means used to assess capabilities for producing grammatical sentences. These methods if relied upon exclusively may lead to underestimates of grammatical competence. To validly relate function to brain anatomy we need behavioural methods that have the requisite scope and sensitivity for testing competence fully. The method we adopt here is *elicited production*, an approach that has been used to good effect in studies of language acquisition in children (Thornton, 1996), and has been applied by our research group to lexical retrieval and sentence formation in adult aphasic speakers with localised lesions (for preliminary reports see Ni, Shankweiler, Conway-Palumbo, Thornton, & Crain, 1998; Ni, Shankweiler, Harris, & Fulbright, 1997). An advantage of a controlled elicited production method is that it enables one to study lexical production and phrase and sentence production under conditions of systematically varying linguistic and pragmatic support without the use of artificial repetition tests. Because of that capability, we maintain that elicited production can test the limits of language competence, as critical for assessing recovery from stroke as it is for language acquisition.

The sources of aphasic speakers' difficulties in sentence formation are still poorly understood. Word retrieval has been the most extensively studied aspect of aphasia. Most word retrieval studies in aphasia have been about noun finding, not about verb finding, yet it is evident that many aphasic speakers show reduction in verb form use (Bastiaanse & Jonkers, 1998; Goodglass, Christiansen, & Gallagher, 1994; Miceli, Silveri, Villa, & Caramazza, 1984). As vehicles for grammatical functions, verbal elements play an essential role in forming and understanding propositions. Verbs are integral to thematic role assignment, and through their subcategorisation possibilities, they are indispensable tools for sentence building. Accordingly, one can expect to find connections between difficulties in retrieval of verbs and their parts and difficulties in formation of sentences. One manifestation would be a reduction in sentence types produced, with avoidance of non-canonical grammatical forms, such as the passive, and avoidance of embedded structures, such as relative clauses. In fact, depletion of passives and of relative clauses have long been recognised as symptoms of agrammatism (Caramazza & Zurif, 1976; Goodglass, 1993).

Connections between verb retrieval and sentence production have rarely been examined either in clinical tests or in research studies. A recent approach to aphasia assessment that attempts to integrate these aspects of function was proposed by Bastiaanse and associates (2003) who presented a test to assess comprehension and production of verbs in and out of sentence context using pictorial materials, and also to assess verb form use in sentence production. This approach is similar in some respects to our use of elicited production in the present study.

In contrast to the failures in production, some success in *parsing* grammatically complex spoken sentences containing passives and relative clauses has been demonstrated in persons with agrammatism (Caplan & Futter, 1986; Linebarger, Schwartz, & Saffran, 1983; Shankweiler, Crain, Gorrell, & Tuller, 1989). Preserved ability to detect anomalies in sentences containing these structures suggests that failure to produce them may not be caused by loss of syntactic knowledge. Processing limitations may be responsible (Crain, Ni, & Shankweiler, 2001). If so, the contextual supports and reduced processing load offered by our elicited production procedure may enable impaired individuals to achieve greater success than would otherwise be possible. Resolving this question is important for achieving a better understanding of the causes of grammatical production difficulties and for developing effective approaches to treatment.

Numerous studies of language abilities in children have demonstrated that attention to aspects of pragmatics can strongly affect performance on psycholinguistic tests designed to elicit particular sentence structures (see Crain & Thornton, 1998, for review). Arguably, there is a presupposition underlying the use of a restrictive relative clause that makes that structure pragmatically felicitous. In this connection, Hamburger and Crain (1982) discovered that when children are asked to comprehend restrictive relative clauses, such as *The dog that scared the cat ate the bone*, it is presupposed that more than one dog be under consideration, either in a picture if it is a picture task, or in the work space in an act-out task. Adult aphasic speakers, because of their impaired processing capacities, may be especially vulnerable to arbitrariness, as in occurrences of language in which this and other *felicity conditions* are not met (see Lukatela, Shankweiler, & Crain, 1995). Pragmatic considerations become important whenever we wish to obtain a valid picture of a person's language capacity.

Applied to the analysis of language deficits in aphasia cases, the elicited production technique enabled us to assess word retrieval in relation to (a) word class, comparing retrieval of nouns and adjectives vs verbs, and (b) word parts, retrieval of stems vs grammatical affixes (morphology). Further tasks were designed to elicit complex grammatical structures, passives, and relative clauses. The intent behind each procedure was to supply rich contextual supports for the production of the designated target word or structure, using visual props and coordinated spoken story scenarios. The goal of each elicitation procedure was for the participant to orally complete the detail of a sentence embedded within a scenario that prompts the target word or structure, which is never presented outright. To maximise the likelihood of that result, the visual and linguistic contexts were manipulated in this way, as discussed in Experiments 1 and 2 below.

In this report we present data from our elicited production measures and conventional aphasia tests for three cases of long-standing aphasia. In each case aphasia is a consequence of major stroke, resulting in massive ischaemic lesions of the left hemisphere with damage to both Broca and Wernicke regions. Each case presents with nonfluent aphasia in varying degrees of severity. All have significant word-finding difficulties and limitations on length and variety of sentence productions. However, when assessed by elicited production, all reveal a surprising amount of recovery in view of the extent of left hemisphere damage. In addition to comprehensive data on lexical and grammatical production, we present in Experiment 3 a detailed anatomical description of each case based on structural MRI. Case studies of language and brain that integrate detailed psycholinguistic findings and detailed anatomic reconstruction of the lesion are still fairly uncommon. Yet, the single-participant approach is especially appropriate for probing anatomical factors in recovery of language function after stroke. Brain topography varies substantially from person to person (Amunts et al., 1999; Ojemann, 1991), and the location of infarcted regions varies among people bearing the same clinical diagnosis (Kimura & Watson, 1989). Effects of both kinds of variation are obscured by averaging.

In considering the essential language brain, classical aphasiology has placed almost exclusive emphasis on two perisylvian regions: Broca's region in the inferior portion of the frontal lobe and Wernicke's region in the posterior, superior temporal region. In contrast recent studies, including some based on normal participants using functional imaging tools, have stressed the additional importance for language functions of extrasylvian portions of the left hemisphere and the homologue areas in the right hemisphere (e.g., Blank, Scott, Murphy, Warburton, & Wise, 2002). Our cases have a bearing on this matter because, as we show, the portions of the left hemisphere that are spared lie mainly in regions that are remote from the Sylvian fissure. Further, in as much as our studies focus on syntactic production and supporting abilities, the findings help fill a void, as there is a dearth of studies that specifically investigate the cerebral basis of sentence production (Indefrey & Levelt, 2004).

The present study is based on a new application of elicited production methodology together with detailed anatomical study of the brain with structural MRI. We succeeded in observing a degree of preserved capability to produce syntactically complex sentences despite pervasive damage to Broca's and Wernicke's regions. The following experiments address these specific questions:

1. Does the elicited production method reveal sparing of language abilities not readily evidenced in spontaneous utterances or on conventional aphasia tests?
2. How does sparing and loss of language function reflect of sparing and loss of brain tissue? Specifically, which language production abilities can survive damage to both Broca's region and Wernicke's region?

PARTICIPANTS

The criteria for participation in the study were as follows:

1. Acute onset of aphasia following major unilateral left-hemisphere stroke
2. Old infarcted lesion; at least 5 years post-stroke.
3. Observational and psychometric evidence of at least some recovery, and an ability to attempt the experimental tasks.
4. Evidence (from the personal histories) of unimpaired function pre-morbidly.

The findings are based on three cases of stable, moderate to severe, nonfluent, agrammatic aphasia. Each participant had normal hearing and vision. Each is a native speaker of English. Each sustained left hemisphere stroke, and each had received conventional speech therapy and had maintained contact with aphasia support groups. None was conspicuously apraxic in speech production. Ages presented below are as of the last testing session.

Case 1: JN

JN was a right-handed female homemaker, age 80, with education beyond college, who suffered a left CVA in 1989. According to the initial speech pathologist's summary, she presented with "moderate-to-severe expressive and mild-to-moderate receptive aphasia characterised by agrammatic verbal output, severe anomia, decreased auditory comprehension skills for complex or lengthy material, and decreased reading and writing skills". Her speech, at each testing, consisted of short, stereotyped phrases with a paucity of function and content words. Word finding was more severely impaired than in the other cases. At the time of this study she displayed only mild residual involvement of the right arm.

Case 2: BN

BN was a female college graduate and former bank officer, age 62, who suffered a minor stroke followed shortly by a major stroke. She exhibited residual hemiparesis affecting both extremities on the right side, and walked with aid of a leg brace. In spite of limited use of right arm and hand, she regularly drove a car equipped with manual controls. BN's speech was moderately agrammatic and dysfluent, but her functional communication was good with moderate impairment of word finding. She reported pre-existing ambidexterity. BN remained physically and socially active until shortly before her death in 2007.

Case 3: HW

HW was a right-handed male high school graduate, age 65, who suffered a major stroke 13 years previously. Prior to his stroke he had been employed as a postal worker. He presented residual hemiparesis affecting both arm and leg on the right side, and walked with the aid of a cane. HW spoke in halting, nonfluent, agrammatic short phrases and showed significant word-finding difficulties. At the time of the study he was physically and socially active, drove a manually equipped car, and lived semi-independently.

Results of standardised aphasia testing are summarised in Table 1. BN and HW were tested on BDAE second edition; JN was tested with the third edition, as noted in the table. Gaps in the table are the result of differences in these two editions of the test. Overall percentile scores on the BDAE ranged from 56% to 71%. Scores for Naming, derived from the BDAE and the Boston Naming Test, second edition (Kaplan, Goodglass, & Weintraub, 2001) ranged more widely, from 10% to 93%.

The investigation consisted of three experiments: two assessments of language behaviour using the elicited production method accompanied by a detailed anatomical description based on structural MRI. Experiment 1 (ELEX) probed participants' lexical abilities, specifically retrieval of nouns, adjectives, and verbs. The test was also designed to assess production of past tense morphology. In Experiment 2 we used the elicited

TABLE 1
Participant profiles based on standardised aphasia assessments

Participants	*JN*	*BN*	*HW*
Boston Naming Test (60)	1	39	38
Boston Diagnostic Aphasia Examination			
Post-onset (years)	13	20	13
Overall percentile**	56.3	70.8	68.1
Naming			
Responsive Naming (30)		26	28
Confrontation Naming (114)		91	105
Animal Naming (23)		9	14
Responsive Naming* (20)	0*		
Special Categories* (12)	7*		
Overall Percentile	10*	83	93
Auditory Comprehension			
Word Discrimination (72)	*64*	62	71
Body Part Identification (20)	*12*	18	20
Commands (20)	*6*	14	3
Complex Ideational Material (12)	*10*	10	9
Words* (37)	33		
Categories: Tools* (10)	10		
Categories: Foods* (10)	10		
Categories: Animals* (10)	10		
Body Parts* (20)	12		
Maps* (15)	15		
Production (Repetition)			
Words (10)		8	9
High Probability Phrase (8)		2	5
Low Probability Phrase (8)		2	3
Single Words* (10)	7		
Nonsense Words* (5)	3		
Sentences	0		

*From BDAE, 3rd edition; all other subtests and values are from BDAE, 2nd edition.

** Averaged scores without "music".

Values in italics are adapted from performance on BDAE-3. Scores in the body of the table are raw scores. Maximum scores are listed in parentheses.

production methodology to assess residual grammatical ability at the sentence level. Experiment 2A (EPAS) was designed to elicit verb in the passive voice, and Experiment 2B (EREL) targeted production of restrictive relative clauses. Experiment 3 was the anatomical study. Methodological details are presented separately with each experiment.

EXPERIMENT 1: ELICITATION OF VERBS, NOUNS, AND ADJECTIVES (ELEX)

Stimuli

The participants were presented with 24 brief stories with accompanying props, each eliciting one of the 12 past tense verbs or a phonologically corresponding noun or adjective, hence the materials controlled phonetic content across word classes (see Ni et al., 1998). The items were quasi-randomised to ensure that members of a homophone pair did not immediately follow one another. Different stories were created to elicit the verb *towed*, as in "towed the car" and the noun *toad*; the verb *blew* and the adjective *blue*, and so forth. Five of the verbs were regular and seven were irregular. Adjectives included derived (e.g., *wrinkled*) and underived (e.g., *blue*) examples, and nouns were all in the singular form. A list of target items and a brief description of the eliciting context for each are provided in Table 2.

For each target word a scenario consisting of an auditory context (a brief story) and accompanying prop(s) was matched with a sentence prompt. The script for the auditory component did not include the target word in any form. For the verb targets the auditory context emphasised completed actions, using the past tense as well as describing the events as happening "yesterday". In addition, the sentence prompt for the verbs included a contrasting verb in the past tense in some cases. Below are representative sentence prompts for verbs, adjectives, and nouns:

TABLE 2
Complete list of items from ELEX, EPAS, and EREL

Verb target	*Action with prop*	*Noun/Adj target*	*Example or prop*
Regular Verb			
pointed	. . .pointed at	pointed	a pointed hat
twisted	. . .twisted the wire	twisted	a twisted wire
wrinkled	. . .wrinkled the clothes	wrinkled	a wrinkled prune
towed	. . .towed a car	toad	an ugly toad
rowed	. . .rowed a boat	road	a winding road
Irregular Verb			
saw	. . .saw a movie	saw	woodworking tool
heard	. . .head a sound	herd	a herd of cattle
read	. . .read a book	red	the color
flew	. . .flew an airplane	flu	sick with the flu
ate	. . .ate a cake	eight	the number
blew	. . .blew out candles	blue	the colour
Passive			
The girl got/was/is being scratched (by the cat)			
The horse was/got/is being ridden (by the man)			
The frog was/got/is being stepped on (by the man)			
The burglar was/got/is being arrested (by the police)			
The catcher was/got/is being pushed (by the pitcher)			
The dog was/got/is being tied up (by the owner)			
The man was/got/is being shaved (by the woman)			
The woman was/got/is punched (by the man/attacker)			
Subject Relative Clause			
The penny is under. . .			
. . .the bear that is holding the fish (1)*			
. . .the rooster that is pecking the bug (3)			
. . .the man that is hugging the boy (4)			
. . .the tiger that is sniffing the bird (7)			
Object Relative Clause			
The penny is under. . .			
. . .the woman that the cat is licking (2)			
. . .the sheep that the frog is riding (5)			
. . .the fox that the butterfly is tickling (6)			
. . .the cow that the dog is riding (8)			

*Numbers in parentheses give the order of presentation.

Sentence prompt for *flew*

Both the spider and the bird got to the top of the tree. The spider climbed to the top and the bird ______.

Sentence prompt for *pointed* (as an adjective)

The graduate's hat is flat on top, and the magician's hat is ______."

Sentence prompt for *toad*

This is a frog [tester points to frog], and this [tester points to toad] is a _____?

Prior to this study the stimuli were presented to individuals with non-impaired language abilities. Target items were readily elicited, with all scores at ceiling. The performance of this control group will not be considered further in our analysis.

Procedure

Each participant was interviewed by one tester and a "confederate", whose role was to add pragmatic valence to the task. Participants viewed toy figurines accompanied by brief stories designed to prompt the target word by completing a leading sentence. There was a single practice item. If the participant began to struggle, attention was drawn to the critical feature of the action or the object, and the prompt was repeated. Phonetic prompts were not used. Items were presented in a quasi-randomised order so that members of a homophonic pair did not immediately follow one another.

This portion of the testing session was audio- and video-recorded. The recordings were later transcribed by the second author. The confederate also took detailed notes of the participants' responses, and two sources were reconciled to produce a unified transcript.

Results

The lexical elicitation procedure revealed partially spared ability to produce nouns and adjectives as well as verb stems and inflectional morphology. Figure 1 details the proportion of correctly produced noun and adjective targets and verbs produced with and without correct inflection. In some cases participants responded with a plausible semantic substitution, but credit was only awarded for the production of the target verbs.

We consider first the retrieval of verb stems. Disregarding absence of and errors of inflection, all participants were able to produce target verb stems on some of the trials. BN and HW produced 7 out of 11 and 7out of 10, respectively. JN showed lower performance, producing correct targets on 4 of 11 trials. On items where BN and HW failed to produce the target, they were able to supply a meaning-preserving substitution in most cases (e.g., "bending" for "twisted", "move to garage" for "towed"), whereas JN had more difficulty conveying any description of the event.

The production of correct inflection proved challenging for all three. JN could not coordinate a correct verb stem with the correct past tense inflection, although analysis of her errors showed that she could produce the *-ing* and past tense inflections on non-target verbs. HW and BN fared slightly better; BN coordinated verb stem and correct inflection on 2 of 11 trials while HW was able to do so on 3 of his 10 trials. When BN did not use the past tense, she produced simple present tense on one trial

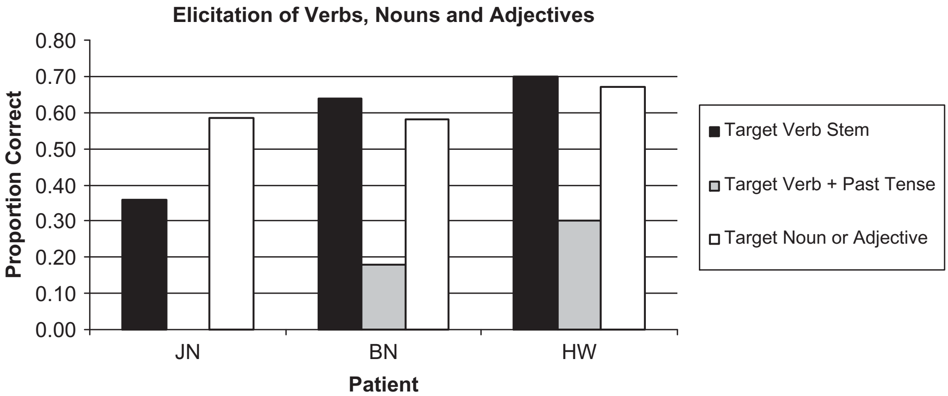

Figure 1. Proportion correct for nouns, adjectives, verb stems, and past tense inflected verbs. Proportions were computed with a total possible of 11. One item was excluded because it was not uniquely felicitous for the target word. HW's proportion was computed from a total of 10, since one item was omitted during test administration. HW was tested with the same materials and same procedure 5 years prior to the reported testing session. His performance on both noun/adjective retrieval and verb retrieval was slightly higher on the first testing. *JN's performance on Target Verb + Past Tense was 0.

and -*ing* on two trials. By contrast, when past tense was not used, HW provided only the bare verb stem.

Participants were more successful at retrieving nouns and adjectives, with even the most severely agrammatic participant (JN) producing the correct noun or adjective on 7 out of 12 trials. On this test she performed at a similar level with the other two: BN produced the target on 7 out of 12 trials and HW produced 8 out of 12. All scored better on nouns than adjectives. Performance on underived adjectives was substantially better than performance on derived adjectives. The two underived adjectives (*red* and *blue*) were successfully elicited from all participants. Derived adjectives, which bear past-tense morphology (e.g., *wrinkled*, *twisted*, and *pointed*), were particularly challenging. Of the three targets, only one instance was successfully produced (by BN). While this suggests a possible substantive difference between these types of adjectives, our sample set is too limited to effectively evaluate this possibility.[1]

EXPERIMENT 2: ELICITATION OF COMPLEX GRAMMATICAL STRUCTURES

Residual ability to produce complex grammar at the sentence level was probed with two structures known to be difficult for aphasic speakers: passive and relative clause (Goodglass, 1993). Both are displacement structures, in which an argument appears in a non-canonical position. In order to produce a passive, the noun that is the patient of the action expressed by the verb must be produced in a displaced position, as the sentential subject.

[1]HW was tested with the same materials 5 years prior to the reported testing session. At that previous testing session he produced one of the derived adjective targets (wrinkled), and made another related substitution ("bent" for "twisted"). At this testing session he was also successful at producing "wrinkled" as a past-tense verb.

Active voice

The man rode the horse

Passive voice

The horse was ridden (by the man)

Linguistic theories have frequently proposed that an association must be established between the grammatical subject (here, *the horse*) and the vacant verbal object position. Inclusion of the *by*-phrase indicating the Agent (the man) is optional. Production of a relative clause likewise involves displacement. In a subject relative, the noun that is being modified must be associated with the subject position of the embedded clause. In an object relative, this noun must be associated with the verbal object.

Subject relative

The rooster that is __ pecking the bug

Object relative

The bug that the rooster is pecking ___

Some researchers claim that individuals with agrammatism have specific syntactic deficits that result in comprehension impairments of displacement structures and rely on heuristic strategies to interpret them (Caramazza & Zurif, 1976; Grodzinsky, 2000). Others provide evidence that difficulties result from processing limitations, and not disruptions of syntactic abilities per se (Crain et al., 2001; Linebarger et al., 1983). Object relatives are observed to be more difficult to comprehend and to produce than subject relatives for both children (Tavakolian, 1981) and adults with aphasia (Grodzinsky, 1989), and also take longer to process by non-impaired adult readers (Ni, Shankweiler, & Crain, 1996). Preliminary reports from our lab using the elicited production method to examine relative clause and passive suggested that aphasic speakers may retain some spared ability to produce these complex structures when supported by the context of discourse (Ni et al, 1997; Crain et al., 2001). The present study extends these findings.

As in Experiment 1, the testing sessions were recorded using audio and video media, which were later transcribed and reconciled with notes made by the confederate. As in the previous experiment, all items for this test were administered to non-impaired speakers, who performed at ceiling. Their scores will not be examined further.

EXPERIMENT 2A: ELICITATION OF THE PASSIVE (EPAS)

Stimuli

To examine the production of passive structures, nine "cliff-hanger" stories were developed in which each of nine verbs to be passivised was presented in the active or infinitival form. At the end of the story, attention was directed to the action and a focused character as the patient of the action. Each story was paired with a line drawing depicting the outcome. In each story three potential agents were introduced, only one of which ultimately carries out the action. These extra characters provided a contrast to the actual agent, a potential pragmatic condition on the use of passive (see O'Brien, Grolla, & Lillo-Martin, 2006).

For example, elicitation of *the girl got scratched (by the cat)* went as follows:

> This is a story about a little girl who likes to play with animals. She loves to play with them, but she is a little afraid that their claws might scratch her. She plays with a dog, and the dog is gentle. Then she plays with a rabbit, and the rabbit is gentle, too. Now she sees a cat. She goes to the cat and starts to play. Let's see what happens.

This was paired with a picture displaying the outcome, which in this instance showed the girl with scratch marks on her hand and the cat in the act of scratching. The passive targets are listed in Table 2.

Procedure

The participant and confederate listened to a story (such as the cat scratching story above) and then the participant (but not the confederate) was shown a drawing depicting the outcome of the story. The examiner then made a comment focusing attention to one feature of the outcome (e.g., "Look what happens to the girl!)" and then prompted, "Now tell Mr. X what happens to the girl at the end." If the participant struggled, a further prompt was provided with the patient as subject, "I'll start and you finish. At the end, the girl . . ."

To give communicative import to the participant's response, the confederate is not permitted to see the picture representing the outcome of the story. The participant must describe the outcome to the confederate, and this is done most felicitously with a passive. Phonetic prompts were not used. If the participant could not supply the target or a substitute, the examiner moved on to the next item. Items were presented in a fixed order.

Results

The passive voice test proved to be difficult for all three participants, yet evidence of residual knowledge of passive structure surfaced. Table 3 gives the types of responses produced. Reponses were categorised into a passive voice hierarchy ranging from complete to partial productions. The target was a full passive with the patient of the action as the subject, an auxiliary, and a verb bearing passive morphology (past participle). If the auxiliary was omitted, as is common in agrammatic speech, it was separated accordingly (e.g., *the girl scratched by the cat*). Another type of response that contained passive-like features was classified as Adjectival Passive (e.g., *The man was*

TABLE 3
Types of responses in passive elicitation

	JN	*BN*	*HW*
Full passive w/auxiliary	0	0	0
Passive w/ auxiliary missing	0	1	1
Adjectival passive	1	2	2
Active sentence with patient as subject	4	2	3
Active sentence with agent as subject	0	4	3
Body gesture	2	0	0

shocked, *The girl was frightened*; see Belleti & Rizzi, 1988, Grimshaw, 1990, Pesetsky, 1995). Two other types of substitutions were observed, including active sentences where the patient was the subject (e.g., *The horse is happy* instead of *The horse was ridden*), and active sentences where the agent was the subject (e.g., *The man get on the horse* instead of *The horse was ridden*). In the former case the response was not a passive but did conform to the task protocol by beginning with the patient of the action as subject. In the latter case, even though the prompt indicated the response should begin with the patient, the sentence began with the noun phrase representing the agent of the action. For each trial, the participants' responses were coded according to the hierarchy. If a participant provided multiple responses for a given trial, we report only the response ranking highest on the hierarchy.

HW and BN each produced one clear example of a verbal passive, but with the auxiliary omitted (see examples below). HW also supplied the optional *by*-phrase once, indicating the agent of the action, which is often referred to as a "long passive".

Verbal Passive with Auxiliary Omitted

Target: The girl was scratched (by the cat)

Tester: Now tell Mr. X what happens to the girl at the end. . .

HW: OK. . .The (uh) girl (uh. . .uh. . .uh) leading (uh) the (the the) cat

Tester: See the claws here.

HW: Yes. (uh) she (um I think) she was (uh) scratch (uh) her.

Tester: Um hum. So the girl. . .

HW: Girl uh [clawing motion]

Tester: with the claws.

HW: claws.

Tester: So let's see if we can put it into a sentence. The girl. . .

HW: . . .**the girl** (uh uh) s**cratched by the** (uh uh) **cat**.

Recall that in the story context that preceded the elicitation prompt the tester did provide the target verb, but did not model either the morphology or the passive sentence structure. BN was also successful at demonstrating passive, but supplied an appropriate substitute for "stepped on" where the agent was clearly implied.

Verbal Passive with Substitution (BN)

Target: The frog was stepped on (by the man)

Tester: Now tell Mr. X what happens to the frog.

BN: The frog sitting in. . .the log. . .and the boy. . .ignorant but walking, and I guess, crushed the frog.

Tester: What do you see?

BN: (uh) stepping out. . .the man stepping out but maybe the frog got away or (uh) stepping and **the frog. . .killed**.

Adjectival Passive with Auxiliary (HW)

Target: The waitress got punched (by the man).

Tester: Now tell Mr. X what happens to the waitress at the end. . .

HW: . . .the man (uh s uh sh uh) struck the waitress (uh uh) she (uh uh druh) drag head by the head and **she was frightened**.

Passives were difficult for all participants. Although the passive voice test, EPAS, was designed to elicit the full passive with an auxiliary verb, none of the participants successfully produced a full passive; yet unmistakable evidence of residual knowledge of passive structure surfaced, at least in HW and BN. These participants showed limited ability to produce passive voice, although omitting the auxiliary. It is notable that HW once supplied the optional *by*-phrase, producing a so-called "long passive".

The bulk of the responses took the form of either an Active Sentence with the Patient as Subject, where the participant is able to satisfy the request to begin the sentence with the patient of the action, or Active Sentence with Agent as Subject. In the later case, even though the prompt for the response called for the sentence to begin with the patient of the action, the participant avoided the patient altogether and placed the agent as subject. JN had the most difficulty with this task. For nearly half the trials, she either relied on gesture or simply failed to produce a meaningful response.

The EPAS methodology also prompted the production of adjectival passives by all three participants. Although not the classic version of the passive, adjectival passives exhibit passive morphology and are a further example of these individuals' use of verb morphology, here in a complex syntactic context. For example, the most impaired participant, JN, produced "the boy is finished because the boy is satisfied". Neither "finished" nor "satisfied" was modelled by the tester. This is rich language from an individual who performs at floor on conventional naming measures and communicates in daily life with only a few stereotyped phrases.

EXPERIMENT 2B: ELICITATION OF RELATIVE CLAUSES (EREL)

Stimuli

For the elicitation of restrictive relative clauses, eight prompting scenarios with figurines were constructed, four designed to elicit a subject relative and four designed to elicit an object relative. The props and stories were designed to support the elicitation of a complement clause control and to be adaptable to support either a subject relative or an object relative. In each case two identical pairs of animate figures were used. For example, for the elicitation of *the rooster that is pecking the bug*, two roosters and two bugs were displayed in the visual context. One pair was the focus of the activity while the second pair was present to make the use of a restrictive relative clause felicitous (see Introduction). A full list of items is provided in Table 2.

Procedure

The elicitation procedure had two parts. At the onset of each trial, a toy figurine (e.g., a rooster) was introduced. It carried out some action (e.g., pecking a bug) and

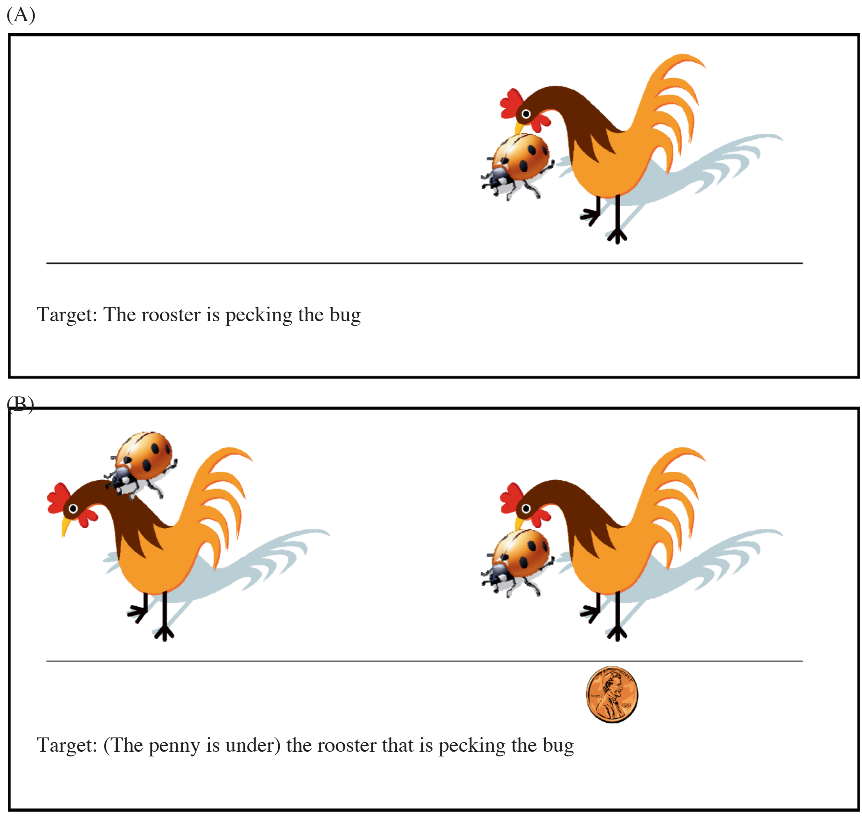

Figure 2. (a) Initial presentation of visual props in EREL. (b) Introduction of extra characters to satisfy pragmatic conditions for use of relative clause. [To View this figure in colour, please visit the online version of this Journal.]

the participant was directed to describe the scene (e.g., *the rooster is pecking the bug*) (see Figure 2a). This present progressive form was elicited to serve as a compliment clause control in the event that a reduced subject relative (where *that* and the auxiliary are omitted) was produced (e.g., *the penny is under the rooster pecking the bug*).

Next a second identical pair of characters was introduced, carrying out a different action (e.g., the bug is biting the rooster). The two primary figurines (here, roosters) are thus distinguished only by the action performed by or upon one of them. The examiner hid a penny underneath one of the figures and prompted the participant to describe to the confederate the location of the penny (see Figure 2). Items were presented in a fixed order.

> The penny is under one of the roosters, tell Mr. X which rooster. You can begin by saying "The penny is under . . ."

If the participant struggled, the examiner could provide additional levels of linguistic support by supplying increments of the sentence, but avoiding the target structure:

(a) The penny is under . . .

(b) The penny is under the rooster . . .

Results[2]

Participants were presented with scenarios in which a restrictive relative clause was highly felicitous. The syntactic embedding of these structures probed the limits on spared grammatical knowledge, and as such was challenging for all participants. Still, the elicited production protocol supported and motivated them, and all completed the task in good humour, and all were able to produce interpretable responses. Responses, detailed in Table 4, showed three types of embedded structure: Full Relative, in which the relative head, *that*, is present (e.g., *the chicken that is pecking the bug*); a Reduced Relative, where *that* is omitted (e.g., *the chicken pecking the bug*); and Substitution, where a subject relative is substituted for an object relative, either by exchanging the relativised character (e.g., *the bug that the chicken is pecking* becomes *the chicken that is pecking the bug*) or by introducing a different verb (e.g., *the bug that the chicken is pecking* becomes *the bug that is stinging the chicken*). Although the fragments produced in the Reduced (Subject) Relative category give the appearance of a simple active where the auxiliary is omitted, they can be distinguished by comparison with the participant's response to the compliment control prompt. In each case where a reduced subject relative was produced to the relative prompt, the participant had produced the corresponding present progressive control at the beginning of the trial (e.g., *the chicken is pecking the bug*). This control shows that in describing the present active, participants produced the present progressive, including auxiliary. By comparison, in the relative context, the reduced relative fragments produced did not include the auxiliary; instead they appear to be

TABLE 4
Types of responses in relative clause elicitation

	JN	*BN*	*HW*
Subject Relative Items (max = 4)			
Produced Full Relative	0	0	0
Produced Reduced Relative	0	2	4
Produced Coordinate	4	2	0
Object Relative Items (max = 4)			
Produced Full Relative	0	0	0
Produced Reduced Relative	0	0	0
Substituted Subject Relative	0	1	1
Produced Coordinate	3	3	2
Produced Prepositional Phrase	0	0	1

[2]A summary of some of the psycholinguistic data (that relating to relative clause elicitation) for one of the participants, HW, was included in an earlier review article which interpreted sentence-processing deficits in aphasia in the light of findings from eye-tracking studies of sentence processing by non-impaired adults, and sentence processing and experimental studies of language in developing children (Crain et al., 2001).

following the ordinary form for a reduced relative clause. A fourth response type, Coordinate Conjunction, was also observed. In this case, the proposition is expressed with two coordinated clauses one naming the relativised noun and the other providing some identifying feature, usually involving the activity intended for the relative clause (e.g., *The penny is under the chicken and the chicken is pecking the bug*).

None of the participants produced a full relative clause (i.e., including *that*). However two, HW and BN, produced structures that demonstrate preserved use of grammatical embedding. Only subject relatives were produced. HW produced reduced relative structures for all four subject relative targets and BN successfully generated a subject relative for two of these targets. JN was not successful at producing even a single subject relative clause, although she found an alternate way to convey the message. JN employed coordination of the propositions rather than embedding. Both BN and JN produced coordinate structures—BN for two of the targets and JN for all four targets. Employing coordination as an alternative to embedding is an attested stratagem for reducing complexity and it reassures us that this elicitation task, while challenging to the language system, is well understood by the participants (Tavakolian, 1981). In one instance HW completed the task by producing a prepositional phrase. Below are examples of some of the responses that were collected.

Subject Relative Correct

Target: The rooster that is pecking the bug.

Tester: Please tell Mr. X what you can see.

HW: The rooster is pecking the. . .b. . .bug

. . . .

Tester: You can see that the penny is under one of the roosters. Please tell Mr. X which rooster.

HW: The penny under **the rooster pecking the bug**.

Subject Relative with Coordinate Conjunction

Target: The penny is under the fox that the butterfly is tickling.

Tester: The penny is under one of the foxes. Tell Mr. X which one.

. . .

BN: **The penny is under the fox. . .um. . .and the butterfly fooling around.**

Target: The penny is under the sheep that the frog is riding.

Tester: You can see that the penny is under one of the sheep. Tell Mr. X which one.

JN: **Penny is under the sheep...and...but...uh. . .frog is over the sheep.**

Object Relative Converted to Subject by Verb Substitution

Target: The penny is under the sheep that the frog is riding.

Tester: You can see that the penny is under one of the sheep. Tell Mr. X which one.

HW: **The penny. . .uh. . .is. . .under the sheep holding the frog.**

Object Relative Converted to Prepositional Phrase

Target: The penny is under the cow that the dog is riding.

Tester: You can see that the penny is under one of the cows. Tell Mr. X which one.

HW: The penny. . .

Tester: The penny. . .

HW: is. . .under the. . .uh. . .cow. . .uh. . . riding. . .

Tester: The penny is under the cow. . .

HW: and. . .uh. . .riding the dog.

. . .

Tester: The penny is under the cow. . .

HW: **with the dog. . .uh. . .(with) above. . .the cow**.

As expected, object relatives were substantially more difficult. None of the participants was able to produce a full or reduced object relative. Yet participants were sometimes able to express relevant facts with appropriate circumlocutions. HW and BN altered the verb and produced a subject relative (e.g., "the sheep that the frog is riding becomes the sheep [that is] holding the frog". In one instance, demonstrated in the example directly above, HW went through several attempts to express the message. First he attempted to convert the object relative to a subject relative. This failed and he then attempted to coordinate using "and". This too failed, and he settled on a prepositional phrase. The dominant response to these items was coordinate conjunction using "and".

Looking across the two grammatical sentential tasks, production of complex syntax was impaired, but not absent in HW and BN. HW produced five examples of reduced relative clauses and a long passive. The more difficult object relatives did tax him, and he substituted a verb that allowed relevant relationships to be expressed without long distance displacement (i.e., across another noun). This strategy may also relate to the response pattern observed in the passive, where it was difficult (but not impossible) for the patient of the action to be the topic. BN showed some spared ability, producing three relative clauses and one example of verbal passive. JN was unable to produce any of the targets, but did show a modicum of spared grammatical ability, producing an Adjectival Passive, and combining sentences using "because" and "and".

EXPERIMENT 3: ANATOMICAL STUDIES

Structural MRI examinations, contemporary with the most recent psycholinguistic studies, yielded a detailed description of the lesion in each case. The imaging data enabled us to relate language function to the location of spared tissue and to static ischaemic lesions. Each case presents a long-standing massive infarct implicating far more of the left hemisphere than the classical perisylvian regions long considered primary for language functions. The clinical test findings and psycholinguistic findings are interpreted in the light of similarities and differences among the three cases in extent of lesion and structures implicated.

MRI method and procedure

All three participants were imaged while lying supine in the magnet with their heads immobilised by a neck support, foam wedges, and a restraining band drawn around the forehead.

BN was scanned in a GE Signa 1.5 Tesla MRI scanner located at the Department of Diagnostic Radiology, Yale University School of Medicine, New Haven, Connecticut. Axial anatomic images were gathered using T1-weighted imaging (FOV, 200 × 200 mm; matrix size, 256 × 256; number of slices, 16; slice thickness, 7 mm; in-plane resolution, 0.78125 × 0.78125 mm; TR, 420 ms; TE, 11 ms; 2 NEX; FA, 90 degrees). High-resolution sagittal anatomic images were gathered using SPGR acquisitions (FOV, 240 × 240 mm; matrix size, 256 × 256; number of slices, 124; slice thickness, 1.5 mm; in-plane resolution, 0.9375 × 0.9375 mm; TR, 24 ms; TE, 4.73 ms; 1 NEX; FA, 45 degrees).

HW was scanned in a Siemens Sonata 1.5T scanner at the Magnetic Resonance Research Center, Yale University School of Medicine, New Haven, Connecticut. Axial anatomic images were gathered using T1-weighted imaging (FOV, 200 × 200 mm; matrix size, 256 × 256; number of slices, 16; slice thickness, 7 mm; in-plane resolution, 0.78125 × 0.78125 mm; TR, 420 ms; TE, 11 ms; 2 NEX; FA, 90 degrees). High-resolution sagittal anatomic images were gathered using MP-RAGE acquisitions (FOV, 240 × 240mm; matrix size, 256 × 256; number of slices, 128; slice thickness, 1.5 mm; in-plane resolution, 0.9375 × 0.9375 mm; TR, 24 ms; TE, 4.73 ms; 1 NEX; FA, 45 degrees).

JN was scanned in a Phillips 3.0T scanner at the Dartmouth Brain Imaging Center, Dartmouth College, Hanover, New Hampshire. Axial anatomic images were gathered using T1-weighted imaging (FOV, 240 × 240 mm; matrix size, 256 × 256; number of slices, 16; slice thickness, 7 mm; in-plane resolution, 0.9375 × 0.9375 mm; TR, 650 ms; TE, 6.6 ms; 2 NEX; FA, 90 degrees). High-resolution sagittal anatomic images were gathered using SPGR acquisitions (FOV, 240 × 240mm; matrix size, 256 × 256; number of slices, 123; slice thickness, 1.2 mm; in-plane resolution, 0.9375 × 0.9375mm; TR, 7.7 ms; TE, 3 ms; 1 NEX; FA, 15 degrees).

All participants were also imaged using a long TR sequence that included spin-density and T2-weighted images (TR = 2000 ms, TE = 30 and 80 ms, field of view 24 cm, imaging matrix 256 × 192, 1 signal average, 5-mm thick slices with a 2.5-mm gap).

Results

Figure 3 presents two sagittal views through the left hemisphere for each participant, showing the infarcted region. Figures 4, 5, and 6 present sequences of axial slices through the cerebral hemispheres for JN, BN, and HW, respectively. Following radiological convention, the left hemisphere appears on the right. In Figures 4 (JN) and 6 (HW) 30 slices are shown. In Figure 5 (BN) fewer slices (16) were available, for technical reasons.

Brain regions were determined to have an infarct if there was hyperintense signal on spin-density and T2-weighted sequences and hypointense signal on T1-weighed sequences, relative to normal-appearing grey and white matter. Table 5 lists cortical and subcortical structures implicated in the left hemisphere infarcts in each participant. The ratings were made by a highly experienced neuroradiologist from our research group (RKF), without prior knowledge of the clinical histories or the present findings. A rating of 1, indicating presence of lesion, was assigned to those regions judged to be implicated, but a positive rating does not imply that the region was destroyed in toto.

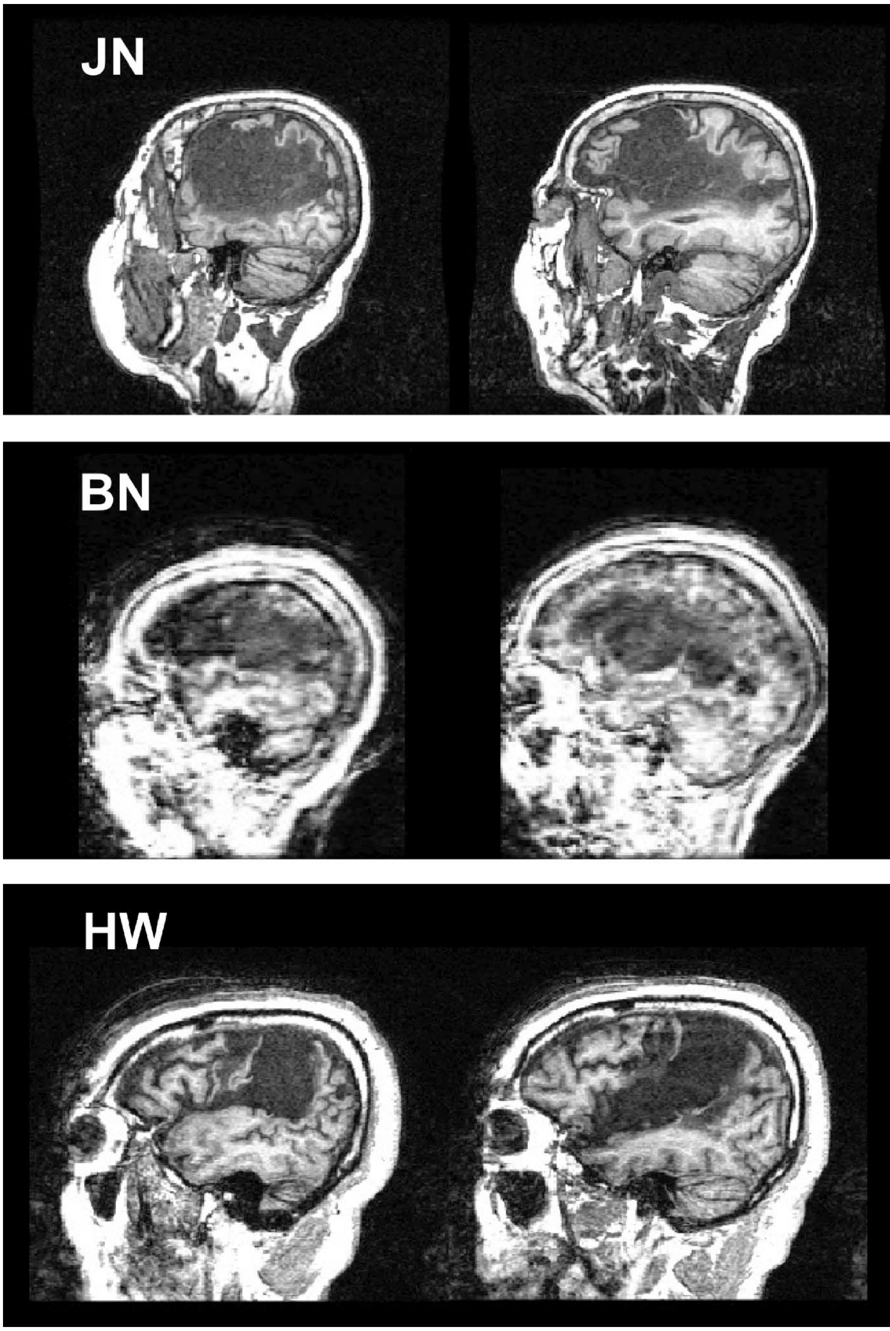

Figure 3. MRI sagittal slices through the left hemisphere for each participant, showing two views of the infarct.

As is apparent from Table 5, each case presents a large left-hemisphere infarct involving the distribution of the middle cerebral artery, implicating cortical and subcortical structures. In each brain the lesion implicates portions of the inferior frontal gyrus (BA 44) and insula, the precentral gyrus/premotor cortex (BA 6, 4), prefrontal

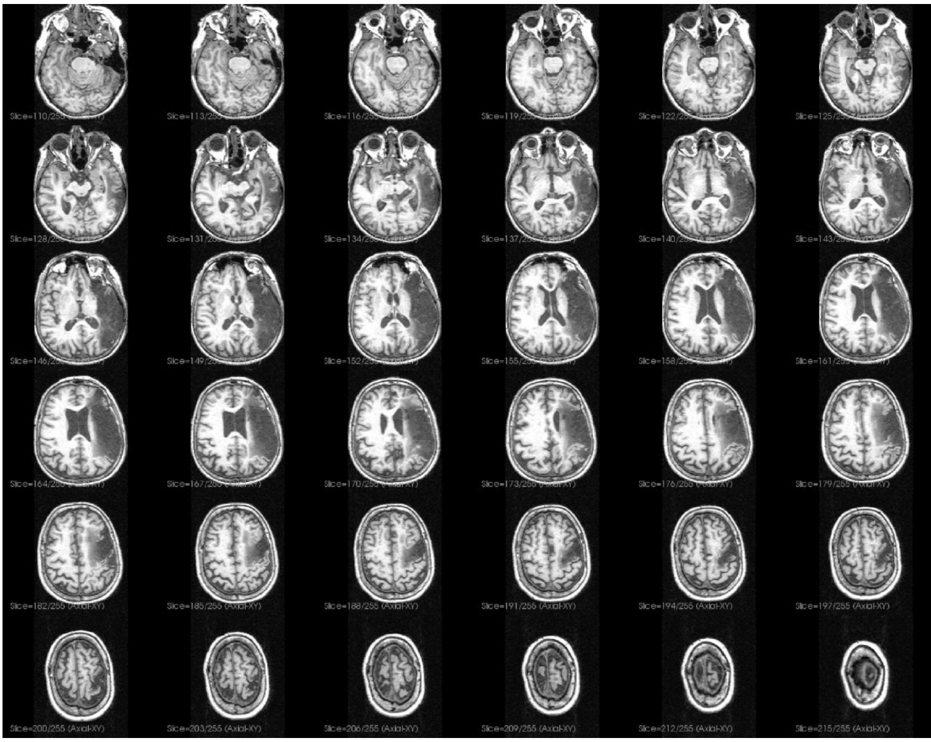

Figure 4. MRI axial slice sequences for JN. T1-weighted, high-resolution images demonstrating the left hemisphere infarct. Left hemisphere is on the reader's right.

(BA 9, 10), dorsolateral frontal region (portions of BA 8, 9, 46, 10, 6), the anterior aspect of the postcentral gyrus (BA 3, 1) is implicated and the posterior aspect of the superior temporal gyrus (BA 22) as well as supramarginal and angular gyri (BA 40, 39. Subcortical extent of the lesion in each case includes portions of the subinsular region, posterior limb of the internal capsule, the posterior portion of the corona radiata, and the superior longitudinal fasciculus.

Table 5 also reveals differences. In JN and BN the damage includes most of Broca's and Wernicke's regions. In HW the lesion included a portion of Broca's region (BA 44, but not 45), and a portion of Wernicke's region (posterior BA 22). JN's cortical lesion extends further ventrally than either of the other cases within the inferior frontal region, implicating portions of the lateral and posterior orbital gyrus. Also, within the temporal lobe her lesion extends to the anterior portion of the superior temporal gyrus, and also includes portions of middle and inferior temporal gyri, regions that were spared in BN and HW. In HW, but not BN, the frontal lesion extends further dorsally to include posterior and medial portions of the superior frontal gyrus, and in the temporal lobe, the middle aspect of the superior temporal region as well as the posterior aspect is implicated. Subcortically, there are differences among the three in distribution and depth of white and grey matter lesion. In JN and BN, but not HW, the subcortical lesion involved the medial subcallosal fasciculus and in BN and HW, but not JN, the middle periventricular white matter is implicated.

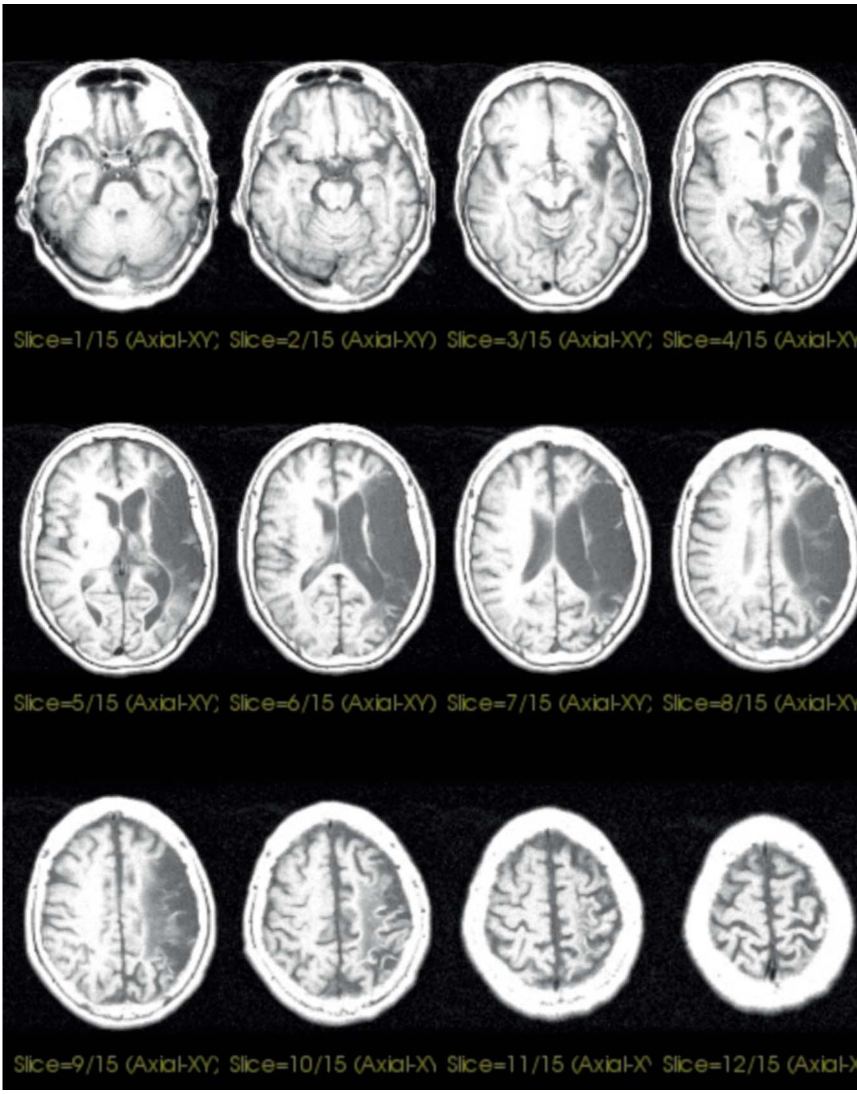

Figure 5. MRI axial slice sequences for BN. T1-weighted, high-resolution images demonstrating the left hemisphere infarct. Left hemisphere is on the reader's right.

Relating anatomy to language function

Each individual was impaired in fluency, had word-finding difficulties, and agrammatism, in keeping with severe damage to both Sylvian and perisylvian cortical regions and underlying subcortical white matter. Despite the fact that each lesion has compromised both Broca's and Wernicke's areas, none of the three could properly be considered globally aphasic. However, because of limitations in MRI image resolution and because both classical language zones are vaguely defined anatomically, we cannot give a quantitative estimate of the extent of damage to Broca's or Wernicke's regions.

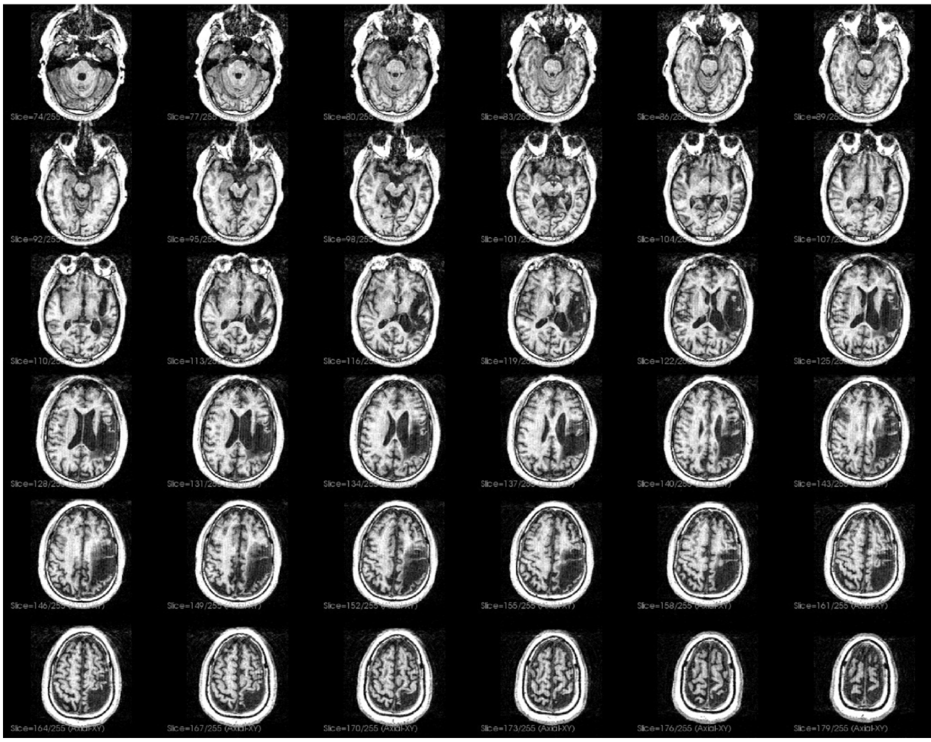

Figure 6. MRI axial slice sequences for HW. T1-weighted, high-resolution images demonstrating the left hemisphere infarct. Left hemisphere is on the reader's right.

JN was the most severely affected in cortical areas, yet unlike the others showed little involvement of right arm and leg. Despite profound left hemisphere damage in a right-handed person, the speech elicitation tasks yielded evidence of some sparing, especially of context-supported word retrieval. In addition to her fragmented, dysfluent speech, JN was severely anomic, as revealed by her near total failure to name pictured objects on the BNT. Nonetheless, she produced a few content words on the picture description task ("Cookie Theft") and in other portions of the BDAE. The pragmatically supported elicited production method of testing yielded more substantial evidence of some residual lexical and grammatical function. JN succeeded in producing some of the target nouns, adjectives, and verb stems in response to verbal semantic cueing by the elicitation procedure; however none of her correct verb stems was correctly inflected. On several occasions, however, JN did inflect verb stems inappropriately with -*ing*. Similarly, on the syntactic tasks she was unable to produce passive sentences or relative clauses, even with support of the elicitation procedure, although she did produce an adjectival passive, which bears passive morphology, in place of a verbal passive. In place of relative clauses she often substituted sentences conjoined by "and". Coordination is a lower level of grammatical function than subordination, but its use to convey relevant meanings suggests that productivity is not wholly lost. Finally, in view of the pattern and extent of cortical damage, JN's comprehension scores (BDAE) were surprisingly high.

TABLE 5
Description of lesions, obtained by structural MRI*

Left hemisphere regions	*JN*	*BN*	*HW*
Cortex			
Inferior frontal gyrus, pars opercularis (BA 44)	1	1	1
Inferior frontal gyrus, pars triangularis (BA 45)	1	1	0
Lateral orbital gyrus (BA 47,11)	1	0	0
Posterior orbital gyrus (BA 11,12)	1	0	0
Precentral gyrus/premotor cortex, anterior-inferior aspect (BA 6)	1	1	1
Precentral gyrus/premotor cortex, anterior-superior aspect (BA 6)	1	1	1
Precentral gyrus/premotor cortex, posterior aspect (BA 4)	1	1	1
Postcentral gyrus, anterior aspect (BA 3,1)	1	1	1
Superior frontal gyrus/SMA and pre-SMA, posterior and medial aspect (BA 6)	0	0	1
Middle frontal gyrus (BA 8, 9, 46, 10)	1	1	1
Superior temporal gyrus, posterior aspect (BA 22)	1	1	1
Superior temporal gyrus, middle aspect (BA 41,42)	1	0	1
Superior temporal gyrus, anterior aspect (BA 52,22)	1	0	0
Middle temporal gyrus (BA 21, 37)	1	0	0
Inferior temporal gyrus (BA 20, 37)	1	0	0
Superior parietal lobule (BA 5, 7)	0	1	0
Lateral occipital gyrus (BA 18, 19)	1	1	0
Supramarginal gyrus (BA 40)	1	1	1
Angular gyrus (BA 39)	1	1	1
Insula	1	1	1
Inferior occipital gyrus (BA 18, 19)	1	0	0
Subcortical			
Subinsular regions (extreme capsule and claustrum, external capsule)	1	1	1
Putamen	0	1	1
Internal capsule anterior limb	1	0	0
Internal capsule genu	0	1	0
Internal capsule posterior limb	1	1	1
Corona radiata anterior	1	1	0
Corona radiata middle/middle periventricular white matter	0	1	1
Corona radiata posterior	1	1	1
Superior longitudinal fasciculus	1	1	1
Medial subcallosal fasciculus	1	1	0
Globus pallidus	0	1	1

*1 = infarct; 0 = no infarct.

Brodmann areas (BA) are provided only as labels for the gross anatomy of the cortical areas listed, not as indicating distinct cytoarchitectonic regions.

Like JN, BN sustained heavy damage to cortical regions that could be expected to impair language function. Moreover, the subcortical depth and extent of BN's lesion is greater than JN's, consistent with her much greater right-sided involvement of arm and leg (Naeser & Palumbo, 1994). The lesion implicates the medial subcallosal fasciculus deep to Broca's area and, posteriorly, the middle periventricular white matter. Lesions occurring in portions of both of these regions have been found to be associated with persisting dysfluency (Naeser, Palumbo, Helm-Estabrooks, Stiassny-Eder, & Albert, 1989). In addition, BN sustained major cortical damage to Wernicke's area in the posterior portion of the superior temporal gyrus that would be expected to impair comprehension—although the lesion spares the middle temporal gyrus, which Naeser, Hel-Estabrooks, Haas, Auerbach, and Srinivasan (1987) find especially relevant to the long-term outcome. Despite having poor indications for recovery of either production or comprehension, BN functioned remarkably well in both modalities. It is likely that her pre-existing ambidexterity, an indicator of bilaterality of language, protected her from more severe deficits.

HW sustained lesser damage to cortical frontal and temporal regions than either of the others, and subcortically his lesion implicates middle periventricular white matter, but spared the medial subcallosal fasciculus. As expected, he outperformed JN on word- and sentence-level tests of elicited production. From the standpoint of the anatomic indicators, he might have been expected to also generally outperform BN. However, he did not always do so. Despite BN's more ominous pattern of left hemisphere cortical damage, she actually bettered HW on one measure of comprehension (BDAE Commands subtest). In production, BN and HW were closely matched on picture naming (BNT), picture description, semantically prompted word elicitation measures, and morphologic and syntactic production, which, in each case, revealed partial success.

The observed partial sparing of production and comprehension capabilities in these cases could point to capacity for transfer of function to the right hemisphere or, alternatively, it could point to the significance of surviving left hemisphere extrasylvian and subcortical tissue. Owing to greater proportion of surviving left hemisphere cortical tissue in cases BN and HW, the presumption of continuing left hemisphere function is stronger for them than for JN. In BN's case, as we noted, evidence of ambidexterity raises a strong possibility of pre-existing bilateral language function. However, in this case there remain areas of sparing within the damaged left hemisphere. The two areas that were spared in BN and HW but were among the infarcted regions in JN are candidates for mediation of their surviving abilities in word retrieval, inflection, and production of complex syntactic structures: These are the middle and inferior temporal region and the inferior prefrontal and dorsolateral frontal region. In the next section we discuss evidence pertaining to functional relations among these cortical zones and we further take note of factors that may influence interhemispheric relations in the aftermath of stroke.

DISCUSSION

Given the goal of accurately gauging spared language capacity after cerebral infarct, production studies have an advantage over studies of comprehension: productions are observable events, unlikely to have occurred by chance in appropriate contexts. Comprehension, on the other hand, is always an inference. Even when the inference is well supported, it is often difficult to confidently assign cause to a specific aspect of the antecedent, be it linguistic or non-linguistic.

In past work, the study of word retrieval and sentence production in aphasia has relied chiefly on three methods: repetition, picture or action naming, presence in a speech corpus. Each of these methods has serious inadequacies. Repetition is arbitrary and unnatural, lacking a normal social context. Picture or action naming introduces extralinguistic demands on visual parsing. Estimates based on a narrative speech corpus tend to underestimate competence because difficult forms tend to be avoided. Elicited production methodology, as we employed it here, does not appear to suffer from any of these drawbacks. We surmised that it would enable us to test the limits of language function under conditions that maximise the opportunity for a word or a structure to occur in pragmatically meaningful contexts. The results we obtained seem encouraging in this respect.

Question 1 was whether the elicited production method could reveal aspects of language function not readily evidenced in spontaneous utterances or with standard methods of aphasia testing, and Question 2 concerned the relations between lesion characteristics and surviving language production capabilities. Overall, the benefits of elicited production are most apparent in testing the most severely anomic participant, JN. For this participant, elicitation by ELEX yielded more output both in quantity of words and in diversity compared with a conventional picture-naming test, the BNT, and compared with sentence prompts from the BDAE. ELEX was intended to provide a meaningful pragmatic context for word use (as distinguished from simple, learned associations) to elicit verbs, nouns, and adjectives, and the procedure did in fact elicit words from each of these target classes in all three participants.

Considering the available data sources pertaining to lexical production, each source yielded a comparable profile for BN and HW. BN produced the correct noun label on 65% of the pictured items on the BNT and 58% on ELEX. HW performed slightly better at 63% on the BNT and 67% on ELEX. JN, however, was much more able to retrieve specific words when tested with ELEX than with pictures. In conversational situations, JN relied primarily on gesture and a few frozen phrases to communicate. Similarly, on the BNT, she was able to correctly name only a single item from the 60-item test (2%) whereas, in contrast, on ELEX she produced 58% of target nouns and adjectives. For speakers with severe word retrieval impairments, such as JN, situating lexical items in a sentence context, incorporating concrete physical objects rather than pictures, and supplying a communicative purpose may be useful for both assessment and intervention.

The inclusion of verb targets as well as noun and adjective targets in the ELEX protocol allowed us to look for possible dissociations among word classes. In individuals with agrammatism, verb production is generally severely limited (Berndt, Mitchum, Haendiges, & Sandson, 1997; Goodglass et al., 1994). But of the three participants, JN alone produced fewer verbs than nouns or adjectives, and the differences across the three word classes were not marked, when verb retrieval is indexed by whether the target stem is produced.[3] The latter finding illustrates another advantageous feature of ELEX: it allowed us to separately address two important questions about verb retrieval: whether the participant is able to retrieve the appropriate verb (stem), and whether he/she is able to inflect the verb appropriately (for past tense). The inflectional system is critical for expressing grammatical and semantic relations. It is telling, therefore, that target past tense inflections were usually omitted by all three participants; in JN's case only nonfinite forms or bare stems were obtained.

Concerning the production of complex sentence structures (Experiment 2), the question we raised in the construction of the two sentence tests, EPAS and EREL, was whether the participant retains the ability to produce sentences (or critical

[3]Homophony across word classes added a control to the design of ELEX. In all instances past-tense verb targets and noun/adjective targets were homophonic pairs, thereby allowing us to rule out one possible source of differences in retrievability that would confound comparisons across word classes (see also Shapiro & Caramazza, 2003). Kemmerer and Tranel (2000) and Bastiaanse et al. (2003) report that homophony between verbs and nouns has a positive influence on verb retrieval.

sentence fragments) in which constituents have moved from their canonical position. Passives and embedded structures are often taken as hallmarks of the generative nature of sentence grammar, and, as such, to provide a critical test of sparing and loss of the sentence grammar. The agrammatism that is variably associated with non-fluent aphasia is marked by impoverishment of syntactic forms (Goodglass, 1993). In view of the severity of their symptoms, we expected that our participants would not produce complex structures such as passives and relative clauses. Not surprisingly, neither type of structure was recorded in the narrative speech sample or in the responses to items on the BDAE. In contrast, the sentence elicitation tasks, EPAS and EREL yielded evidence of partial success, again by BN and HW, for whom production of complex syntax was impaired but not absent. JN did not produce either kind of structure.

No participant produced a full relative clause of either type that included the relative pronoun, *that*. However, BN and HW produced subject relatives in reduced form, demonstrating preserved use of grammatical embedding. Object relatives were generally more difficult than subject relatives, as observed elsewhere in cases of agrammatic aphasia (Grodzinsky, 1989) and also young children (Tavakolian, 1981). BN and HW each produced subject relative substitutes for objective relatives, but their dominant response to these items was to employ coordination of propositions rather than embedding. JN, in keeping with the sparse output from elicitation of verb morphology and the passive, did not produce any instance of a relative clause, although she sometimes also used coordination to approximate the message.

Evidence that core fragments of displaced grammatical structures could be elicited in participants (BN and HW) who were not observed to produce these structures in ordinary communicative situations is a strong indication that the actual principles of passive and relative clause formation may be spared even when performance is severely compromised. The generally agrammatic pattern of their speech may reflect not a loss of syntactic knowledge, as such, but instead be caused by processing and output limitations. Elsewhere we have maintained that the elicitation method reduces processing demands associated with production and comprehension of these complex structures by creating rich contexts that make the occurrence of the target structure pragmatically appropriate (Crain et al., 2001; Ni et al., 1997, 1998; Thornton, 1996). The results of the present study are consistent with this interpretation.

Concerning Question 2, the relations between lesion characteristics and surviving language production capabilities, it was shown that in each case the lesion compromised some portion of both Broca's region within inferior frontal gyrus and Wernicke's region in the posterior portion of the superior temporal gyrus, as well as variable portions of extrasylvian cortex and underlying subcortex. A challenge is to explain the behavioural data in each case and the differences among them in lexical, morphological, and syntactic function in terms of the brain structures compromised and structures spared.

In this connection it could be expected that differences in the subcortical extension of the lesion would explain in part some differences in residual production capabilities that we observed. As noted, Naeser and her colleagues point to the importance of two subcortical pathways, each considered to play an important role in speech production, and which, together, have predictive value for recovery of propositional speech: the medial subcallosal fasciculus and the middle portion of the periventricular white matter. When a lesion is present in both of these two portions of subcortical white matter, persistent nonfluent speech, limited to stereotypies, has been the rule (Naeser et al., 1989). BN is the only one of the three cases that was judged to have a lesion implicating both regions but, as we noted, her recovery was remarkably good, probably because of a pre-existing bilateral organisation. JN showed the least recovery of spontaneous speech, but her lesion involves the medial subcallosal fasciculus but not middle periventricular white matter.

We also acknowledged the likelihood that some or all surviving language function in these cases may be mediated by the intact right hemisphere (Kinsbourne, 1971, 1998). This seems especially likely in JN, whose surviving language behaviour consists of single words and formulaic speech, which may or may not be used propositionally. This picture resembles what has been reported in cases of complete surgical removal of a dominant left hemisphere (Burklund & Smith, 1977). In fact, JN's left hemisphere damage is so massive that it might be considered nearly tantamount to hemispherectomy. The weight of evidence suggests that production, especially syntactic production with ability to express propositions, tends to be the most strongly left-lateralised aspect of language and, plausibly, the least likely to become re-established in the right hemisphere after left hemisphere damage (Code, 1997; Kinsbourne, 1998). But to conclude that only the right hemisphere is contributing to JN's remaining language function would be premature since we had no way to directly evaluate the functional contribution either of the right hemisphere or perilesional remnants of the left hemisphere.

From the standpoint of functions that showed significant recovery, the case for left hemisphere mediation of surviving language function is ostensibly stronger for BN and HW. As we saw, each of these participants showed some significant sparing of lexical and grammatical ability, and ability, though impaired, to use speech propositionally.[4] However, the neurobiologic factors that would favour a better outcome for BN and HW are not the same: BN because of the likelihood of pre-existing bilaterality of language, and HW because he sustained only partial damage to Broca and Wernicke regions, less than the others and less damage to extrasylvian cortex as well.

As for word production, we noted that JN alone failed to produce names of pictured objects on the BNT. Unlike in BN and HW, JN's lesion includes a large portion of the temporal lobe, implicating portions of middle and inferior temporal gyri that are spared in BN and HW. Moreover, JN's lesion includes the inferior occipital gyrus, spared in the others. It is likely that her lesion includes critical portions of the visual association cortex and also portions of the inferior frontal region. As noted in a recent meta-analysis of neuroimaging studies of word production in normal individuals by Indefrey and Levelt (2004), the latter have been reliably activated by picture naming. In addition, the high frontal lobe extension of the lesion in JN likely encroached on a region located in dorsal premotor cortex that cortical stimulation studies find to be strongly activated by picture naming (Duffau et al., 2003; Ojemann, 1991). Although she failed in picture naming, we showed that JN had some success

[4]It has often been pointed out that the interhemispheric distribution of language functions varies widely from person to person for reasons that are still only partially understood. One known source of variability is handedness. Because BN was judged to have been ambidextrous before her stroke, there is reason to ask whether in recovery she may have benefited from a pre-existing bilateral organisation of language, a condition that sodium amytal studies have shown can be a reality in some (mainly) non-right-handed individuals (Rasmussen & Milner, 1977). BN did indeed show an unexpected amount of recovery of both production and comprehension.

on multimodally elicited word generation (ELEX). On generation tasks, imaging studies of verbally cued word retrieval in speakers with normal language abilities have demonstrated widespread left frontal involvement and, variably, temporal and parietal involvement depending on the task (Indefrey & Levelt, 2004; Klein, Milner, Zatorre, Meyer, & Evans, 1995; Warburton et al., 1996). It is true, of course, that not all regions active during a given function may be essential for that function. Lesions associated with impairments in word retrieval for verbs have been found to overlap maximally in the posterior portion of left IFG and neighbouring insula, and for concrete object names in the inferior temporal lobe (Tranel, Adolphs, Damasio, & Damasio, 2001). In each of our participants the lesion implicates portions of IFG and insula (JN's lesion having the greatest extent ventrally and posteriorly), but sparing the middle and inferior temporal lobe in participants BN and HW. These differences, perhaps working in concert, may explain their stronger word retrieval performance on ELEX (Heiss, Kessler, Thiel, Ghaemi, & Karbe, 1999).

Inflectional errors are among the best documented and most conspicuous deficits in people with the symptom of agrammatism (Goodglass, 1993). Our set of tests allowed us to compare production of past tense across three structures: marking the verb as a description of a past event in ELEX, production of a derived adjective in ELEX (e.g., *wrinkled*), and production of the past participle in EPAS. Not surprisingly, in view of the symptom picture, all our participants had difficulty producing correct past inflections. BN and HW were modestly successful with past tense in ELEX, showed some limited success in producing derived adjectives, and each produced an instance of the passive. It is especially noteworthy that JN failed to produce *any* appropriate past tense inflections in response to the ELEX elicitation procedure. Imaging studies on non-impaired participants indicate that Broca's area and underlying white matter regions are critically active as inflections are produced. A well-controlled study by Sahin, Pinker, and Halgren (2006) showed that a network of left premotor regions implement inflectional features, including Broca's area 44/45 and more inferiorly area 47, and a portion of the superior frontal gyrus. In view of these findings it is to be expected that our participants would make errors in inflecting verbs. JN's more extensive lesion in the inferior frontal region may explain her complete lack of success. This is consistent with the possibility that left inferior frontal cortex is essential for selecting a morphological form (Hillis, 2006) that fits a particular morphosyntactic role (in this case, verb inflected for past tense). An alternative proposal suggests that some agrammatic speakers' difficulties with past-tense inflected forms are not a problem with morphology per se, but reflect a more general difficulty in referring to past events (Bastiaanse, 2008).

In syntactic production, as with past-tense inflectional morphology, the same relations are found among the three participants, with partial success shown by HW and BN, and with JN showing little evidence of spared knowledge of the passive or of relative clause structures even with the support of the elicitation methodology. Imaging studies on speakers with normal language function find that inferior frontal cortex is sensitive to complexity of syntactic encoding in language production (Indefrey, 2001; Shankweiler et al., 2008). There are few anatomically detailed lesion studies on syntactic production deficits that could give guidance and, especially in view of the ambiguities in interpretation of lesion overlap studies, we are impressed with a finding resulting from temporary hypoperfusion and reperfusion apparently confined to Broca's area that showed, in turn, impairment and recovery of motor planning of speech articulation and complex sentence grammar (Davis et al., 2008). Although our own findings on partial sparing of grammatical functions argue against equating Broca's area with syntax, many findings point to the centrality of Broca's region and its neighbourhood for several abilities that are important for sentence formation.

Speech apraxia in these participants was notable by its absence. This might be considered surprising because of the definite, though variable, association of phonological production impairment with other features of nonfluent aphasia (Shankweiler & Harris, 1966). As for the anatomy, imaging studies find that speech articulation and speech planning probably depend on a network of regions in the left hemisphere, including parts of Broca's area, the pre- and post-central face area (Hillis et al., 2004) and underlying insula (Dronkers, 1996), all regions damaged in our participants. It is possible, of course, that some or all of our participants were apraxic during the early post-stroke period and subsequently recovered articulatory function.

In summary, studies of language production based on controlled elicited production methodology, coordinated with anatomic data from MRI, from three cases of long-standing, nonfluent aphasia showed evidence of surprising sparing or recovery of productive language function despite large left hemisphere infarcts that destroyed much of what is conventionally regarded as the language brain. In two participants, BN and HW, no language ability we assessed could be considered totally lost. A significant degree of spared productive capability in HW's case may point to lesser damage to Broca's and Wernicke's regions, but also to the likely importance of portions of the left hemisphere remote from Broca and Wernicke regions (Blank et al., 2002). In BN better recovery may likely reflect pre-existing bilateral organisation. JN, on the other hand, in whom damage to the left hemisphere included many portions of Sylvian and extra-sylvian cortex, including Broca's and Wernicke's regions, was more severely impaired. Beyond preserved semantic intent, some quite limited word retrieval possibilities, and surprisingly good auditory comprehension, at least at the lexical level, were observed. She presented little evidence of surviving morphosyntactic function on production tasks, failing to inflect any verb appropriately on the past-tense elicitation task and failing to produce complex syntactic structures even with extensive prompting. The findings in this case prompted the question of whether the remaining language function is based in the right hemisphere.

Overall, this study showed how use of the elicited production method can advance basic knowledge by enabling more accurate assessments of what is spared and what is lost after damage to specific brain regions. In addition, this methodology enables patterns of sparing and loss in aphasic language to be understood in relation to psycholinguistic findings from normally developing children and adults with normal language function (Crain et al., 2001). It is also potentially advantageous from a clinical standpoint—to motivate treatment programmes and evaluate their effectiveness. Unlike conventional aphasia tests, and even analytically detailed procedures such as VAST (Bastiaanse et al., 2003), the elicitation methods we have described were explicitly designed to observe pragmatic constraints on use of particular structures (Crain & Thornton, 1998; Hamburger & Crain, 1982). If used in treatment, these procedures could form a bridge between stereotyped, artificial testing situations and the give and take of normal social exchange.

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