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Unimpaired sentence comprehension after anterior temporal cortex resection

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Abstract

Functional imaging studies have demonstrated involvement of the anterior temporal cortex in sentence comprehension. It is unclear, however, whether the anterior temporal cortex is essential for this function. We studied two aspects of sentence comprehension, namely syntactic and prosodic comprehension in temporal lobe epilepsy patients who were candidates for resection of the anterior temporal lobe.

Methods: Temporal lobe epilepsy patients ($n = 32$) with normal (left) language dominance were tested on syntactic and prosodic comprehension before and after removal of the anterior temporal cortex. The prosodic comprehension test was also compared with performance of healthy control subjects ($n = 47$) before surgery.

Results: Overall, temporal lobe epilepsy patients did not differ from healthy controls in syntactic and prosodic comprehension before surgery. They did perform less well on an affective prosody task. Post-operative testing revealed that syntactic and prosodic comprehension did not change after removal of the anterior temporal cortex.

Discussion: The unchanged performance on syntactic and prosodic comprehension after removal of the anterior temporal cortex suggests that this area is not indispensable for sentence comprehension functions in temporal epilepsy patients. Potential implications for the postulated role of the anterior temporal lobe in the healthy brain are discussed.

Keywords: Anterior temporal cortex; Syntax comprehension; Prosody comprehension; Linguistic prosody; Affective prosody

1. Introduction

Comprehension of sentences requires understanding not only of the rules for combining words into phrases and sentences (syntax), but also of prosodic content. Prosody concerns the modulations of speech with respect to pitch, loudness and length that can indicate lexical, syntactic (e.g. phrase boundaries), semantic (e.g. type of proposition, contrast), and affective properties of utterances. Functional imaging studies investigating language report increased activity in the anterior temporal cortex during sentence comprehension tasks (Crinion, Lambon-Ralph, Warburton, Howard, & Wise, 2003; Giraud et al., 2004; Humphries, Binder, Medler, & Liebenthal, 2006; Humphries, Willard, Buchsbaum, & Hickok, 2001; Maguire, Frith, & Morris, 1999; Mazoyer et al., 1993; Noppeney, Price, Duncan, & Koepp, 2005). As sentence comprehension involves processing of syntax and of prosody (Cutler & Ladd, 1983; Lakshminarayanan et al., 2003; Speer, Crowder, & Thomas, 1993), the anterior temporal lobe has been attributed an important role in these functions (Indefrey & Cutler, 2004).

An extensive review of the neural basis of prosody indicated that the anterior temporal lobe may not be the sole contributor to prosodic comprehension. The posterior temporal lobe as well as subcortical structures also seem to be critical for comprehending prosodic cues (Baum & Pell, 1999). In addition, a recent functional MRI study reported an association between temporal lobe activity and processing of syntactic and prosodic information but could exclude involvement of other structures such as the thalamus, Heschl's gyrus, and posterior parts of the medial and superior temporal gyrus (Humphries, Love, Swinney, & Hickok, 2005). The fact that multiple regions seem to be involved, raises the question whether contribution of the anterior temporal cortex is necessary for processing syntactic and prosodic information.

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Functional imaging studies cannot distinguish between involved and indispensable cerebral areas for the processing of syntax or prosody during sentence comprehension. Lesion studies, by contrast, in which assessment of language takes place before and after surgical removal of the anterior temporal cortex, can in principle determine whether these areas are indispensable. In a previous lesion study we found no differences in syntactic comprehension between patients in whom the left anterior temporal lobe was removed to cure an intractable epilepsy, and healthy control subjects (Hagoort, Ramsey, Rutten, & van Rijen, 1999). Typically, temporal lobe epilepsy (TLE) patients show a decline in memory indices after unilateral anterior temporal lobe resection (Alpherts, Vermeulen, van Rijen, da Silva, & van Veelen, 2006; Bell & Davies, 1998; Hermann, Seidenberg, Haltiner, & Wyler, 1995). Confrontation naming is well-known to be affected by removal of the anterior temporal cortex (Bell, Davies, Hermann, & Walters, 2000; Davies et al., 1998; Hermann et al., 1999; Saykin et al., 1992). Here we tested temporal lobe epilepsy patients before and after resection of the anterior temporal lobe on specific tasks of syntactic and prosodic comprehension. Presurgical performance on these tasks was compared to healthy controls who were matched to patients for age and education. We posed two hypotheses to be tested with regard to anterior temporal lobe function. First, based on our previous study we postulated that syntactic comprehension does not depend on the anterior temporal lobe of the language-dominant hemisphere, hence that removal would not cause a decline of this function. Second, based on imaging studies we hypothesized that anterior temporal lobe does subserve prosodic comprehension, and that therefore resection would cause at least some loss in this element of sentence comprehension.

2. Methods

2.1. Subjects

Thirty-two (16 left, 16 right) temporal lobe epilepsy (TLE) patients who were candidates for unilateral anteromedial temporal lobe resection for the relief of medically intractable epilepsy and 47 healthy controls participated in this study. The mean duration of epilepsy before surgery was 18.2 (S.D. = 13.6) years in left, and 18.8 (S.D. = 12.2) years in right TLE patients. The onset of epilepsy was at age 18.8 (S.D. = 11.2) in left and at age 19.8 (S.D. = 12.1) in right TLE patients. The patients were admitted through the Dutch Collaborative Epilepsy Surgery program and had surgery at the University Medical Center Utrecht.

All subjects had Dutch as their first language. All gave informed, written consent to participate in this study according to the Medical Ethical Committee of the University Medical Center Utrecht (Declaration of Helsinki, Amendment of Edinburgh, Scotland, 2000). All patients were left hemisphere dominant for language as measured by a bilateral intracarotid sodium amytal test (Rutten, Ramsey, van Rijen, Alpherts, & van Veelen, 2002; Wada & Rasmussen, 1960). Thus, all left temporal lobe epilepsy patients were operated in their dominant hemisphere, and all right temporal epilepsy patients were operated in their non-dominant hemisphere.

Healthy right-handed subjects without known neurological problems served as a control group for the prosody comprehension tasks. Tables 1a and 1b present the gender distribution and level of education (Dutch education system categorized into levels from 1 = less than 6 years of primary education to 7 = academic schooling (Verhage, 1964)) for patients and controls. The groups did not differ significantly with respect to age (GLM, $F(2, 76) = 0.5$, NS) and educational level (Kruskall–Wallis, $\chi^2 = 2.8$, d.f. = 2, NS).

The operation involved the removal of 3.5–4.5 cm of the neocortex of the anterior temporal lobe and a surgically complete amygdalo-hippocampectomy. The extent of the resection was measured during surgery, and was confirmed by post-operative imaging. Six months after surgery there were no changes in IQ. One (non-dominant) patient did not participate in post-operative testing.

2.2. Psycholinguistic assessment

Psycholinguistic assessment included syntactic and prosodic comprehension tasks.

Testing of the patients was done shortly before, and 6–8 weeks after operation. The patients were administered the Dutch version of the Aachen Aphasia Test (AAT) (Huber, Poeck, Weniger, & Willmes, 1983), a syntactic comprehension test (Huber, Klingenberg, Poeck, & Willmes, 1993; ter Keurs, Brown, Hagoort, & Stegeman, 1999) and a series of in-house developed prosody comprehension tests.

2.2.1. Aachen Aphasia Test (AAT)

The AAT contains subtests for single word and sentence understanding in the auditory and visual modality, subtests for word and sentence repetition, naming of objects and situations, writing, the Token Test, and a standardized way of collecting a sample of spontaneous speech (Huber et al., 1983).

2.2.2. Syntax comprehension

The test for syntactic comprehension is a Dutch adaptation of a German test of syntactic comprehension (Huber et al., 1993; ter Keurs et al., 1999; Wassenaar, Brown, & Hagoort, 2004). In this syntactic task, subjects have to select one of four target pictures on the basis of an auditorily presented sentence. The syntactic test consisted of five types of sentences in Dutch (a total of 72 items), which differed in their degree of syntactic complexity. The first type consisted of active, semantically irreversible sentences (“The girl with the ribbon carries the ball.”). The second type consisted of active, semantically reversible sentences (“The man with the present kisses the woman.”). The third type was simple passive sentences (“The man with the present is kissed by the woman.”). The fourth type were sentences with an active subject relative clause (“The man who kisses the woman has a present.”). The most complex sentence type consisted of sentences with a passive subject relative clause (“The woman who is kissed by the man has a present.”). If the subject explicitly asked for a repetition, the sentence was read again. Responses were scored on a 3-point scale: 2 points for correctly matched sentences, 1 point for sentences that were correctly matched after self-correction and for sentences that were presented twice, and 0 points for incorrectly matched sentences. The maximum score was 144.

2.2.3. Prosody tasks

The prosody battery tests a patient’s ability to identify spoken affective and linguistic prosody and consists of four subtests: a word stress detection task, a contrastive stress detection task, a statement–question differentiation task and an affective prosody task. Example stimuli are shown in Table 2. The stimuli for the first three tasks were recorded from a speech therapist. The affective prosody stimuli were recorded from a professional actress. The speech stimuli were recorded with a 44.1 kHz sampling rate and were delivered to the subject via two loudspeakers set to a volume that was comfortable to the subject. These tests were validated with a sample of healthy volunteers and were administered by means of a computer. In all tasks, the absolute number of errors was counted.

2.2.3.1. Word stress detection. In the word stress detection task subjects heard two bisyllabic words of similar consonant–vowel structure which were matched for frequency of use in common language. The words were obtained from the CELEX lexical database (Baayen, Piepenbrock, & Rijn, 1993), and include naturally different stress patterns not deducible from basic linguistic rules. The task was to decide whether the stress was on the same or a different syllable. A total of 20 word pairs were presented.

2.2.3.2. Statement/question differentiation. In the statement–question task, subjects heard active sentences spoken as a statement (lowered pitch in the end) or question (raised pitch in the end), and had to

Table 1a
Patient demographics

Patient no.	Sex	Age	Side of epilepsy and operation	Level of education[a]	Age of epilepsy onset	EHI	Full scale IQ	Verbal IQ	Performal IQ	Pathology	Medication
1	M	37	Left	3	17	0.8	71	72	74	MTS	lam, clo
2	M	54	Left	5	4	1.0	108	110	98	Cortical dysplasia	val, lam, car
3	M	34	Left	5	10	0.3	108	102	114	Dermoid cyst	car, phe, clo
4	M	27	Left	5	11	1.0	111	89	116	Astrocytoma	val, lam, lev, oxcar
5	F	36	Left	5	18	0.1	121	116	120	MTS	car, lev
6	F	32	Left	5	14	−0.6	118	121	108	MTS	gab, oxcar
7	F	25	Left	5	10	−0.5	122	113	130	Diffuse astrocytoma	top, clo
8	F	36	Left	5	16	−0.7	125	122	120	MTS	car
9	M	20	Left	6	13	0.4	107	100	114	Astrocytoma	oxcar, lev
10	M	23	Left	6	21	1.0	114	105	120	Migration abnormality	lam, lev, car
11	F	22	Left	6	20	0.9	111	105	116	Pilocytic astrocytoma	oxcar
12	M	59	Left	6	50	1.0	119	122	112	Gliosis	car, top
13	M	56	Left	5	22	1.0	115	111	118	MTS	lev, car
14	M	40	Left	4	12	1.0	115	103	128	MTS	oxcar, clo
15	M	32	Left	7	30	1.0	118	111	124	MTS	clo, lev, car
16	F	37	Left	4	33	0.9	110	102	118	MTS	car, lam
17	M	36	Right	5	33	0.7	113	110	116	MTS	lam, car
18	F	39	Right	6	14	0.9	129	128	120	MTS	oxcar, lam
19	F	48	Right	6	16	0.8	133	131	124	Hamartoma	oxcar
20	F	39	Right	5	1	0.9	109	113	96	MTS	phe, oxcar, lev, clo
21	M	51	Right	3	26	−0.6	97	105	88	MTS	lam, clo
22	F	40	Right	5	10	−1.0	102	102	102	MTS	clo, phe, car
23	M	34	Right	6	16	0.8	130	122	134	Ganglioglioma	phe
24	F	44	Right	5	38	1.0	114	117	108	Microdysgenesis	lev, oxcar,
25	F	54	Right	5	44	0.5	125	133	110	Cavernous hemangioma	car
26	M	33	Right	6	18	1.0	97	97	99	Ganglioglioma	lam, oxcar
27	F	38	Right	5	30	0.5	101	102	100	MTS	lam, top
28	M	40	Right	6	11	0.8	123	108	134	MTS	lev, car
29	M	21	Right	4	13	0.0	86	88	80	Ganglioglioma	phe, gab
30	F	39	Right	4	3	−1.0	107	93	124	MTS	car, clo
31	F	29	Right	4	25	1.0	104	102	100	DNET	phe
32	F	25	Right	5	19	0.8	118	110	126	MTS	lev, oxcar

M = male; F = female; EHI = Edinburgh Handedness Inventory (Oldfield, 1971); MTS = mesiotemporal sclerosis; DNET = dysembryoplastic neuroepithelial tumor; lam = lamotrigrine; clo = clobazam; val = valproate; car = carbamazipine; oxcar = oxcarbazepine; phe = phenytoin; gab = gabapentin; top = toparimate; lev = levetiracetam.

[a] Verhage (1964).

Table 1b
Summary statistics for the patients (pre-operative) and the control group

Group	Sex		Age (years)	Level of education[a]	Age of epilepsy onset		Duration of epilepsy (years)	Full scale IQ	Verbal IQ	Performal IQ
	F	M	Mean (S.D.)	Median (range)	Mean (S.D.)	Median (range)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)
Dominant	6	10	35.6 (11.8)	5 (3–7)	18.8 (11.2)	16.5 (4–50)	18.2 (13.6)	112.1 (12.2)	106.5 (12.8)	114.4 (13.1)
Non-dominant	10	6	38.1 (8.8)	5 (4–6)	19.8 (12.1)	17.0 (1–44)	18.8 (12.2)	111.8 (13.7)	110.1 (13.3)	110.1 (16.1)
Normal control	30	17	34.5 (13.3)	5 (2–7)				N/A	N/A	N/A

[a] Verhage (1964).

decide whether they heard a question or a statement. Forty sentences were presented.

2.2.3.3. Contrastive stress detection. The contrastive stress detection task consisted of 28 sentences containing three noun phrases. With stress on one of the three noun phrases, each sentence thus had three different spoken versions, resulting in slight differences of meaning (cf. The *doctor* got a present from his wife; The doctor got a *present* from his wife; The doctor got a present from his *wife*). After acoustic presentation, subjects had to decide which question matched the presented sentence (e.g. Who got a present from his wife?; What did the doctor get from his wife?; From whom did the doctor get the present?). The questions were presented visually on a computer.

2.2.3.4. Affective prosody. The affective prosody task consisted of sentences of semantically neutral content, which were spoken by a professional actress with affective prosody indicating different emotions. A total of 28 sentences with prosody indicating sadness, happiness, disgust and anger were presented. Upon hearing a sentence, subjects had to choose the emotion that they thought matched the sentence (sad, happy, disgust, angry and "don't know"). Deviations from the intended emotion were counted as errors.

3. Statistical analysis

For all prosodic comprehension tests, the number of errors were analyzed. The AAT and Syntax comprehension test scores were compared to norm scores. The pre-operative measures of the prosody battery were evaluated by separate one-way ANOVA, with patient and control groups (three levels: healthy, left, right) as a between subject factor.

To test the effect of anterior temporal lobe resection in the patient groups, scores were evaluated by means of repeated measures ANOVA for each of the AAT subtests, syntactic comprehension subscores and the four prosody measures, with time (two levels: pre-operative, post-operative) as a within subjects factor and group (two levels: dominant (left temporal), non-dominant (right temporal)) as a between subjects factor. As we were interested in detecting even mild potential deficits, we adopted a liberal statistical approach by not correcting for multiple comparisons.

4. Results

4.1. Pre-operative comparison to healthy controls

The pre-operative scores of patients on the AAT and the test for syntactic comprehension were all in the normal range. There were no significant differences between the dominant and non-dominant temporal lobe epilepsy groups. See Tables 3 and 4.

The patient's presurgical prosody scores were compared to the control group. There were no significant differences between groups for the linguistic prosody measures (word stress, statement–question differentiation, and contrastive stress) (see Table 5). There was a significant effect of group for affective prosody comprehension ($F(2, 76) = 10.1$; $p < .001$). A post hoc F^2 analysis (item analysis) confirms this effect ($F_2(2, 54) = 13.8$; $p < .001$). Post hoc testing between the groups (LSD) showed that both patient groups differ from the control group, but that there was no difference between the dominant and non-dominant patient groups. The majority of deviant answers in the patient group occurred in the, "angry" and "sad" items (75% of the

Table 2
Example stimuli of prosody tests

Example stimuli of porsody tests

Stimuli	***Choice options (correct answer)***

A) Word stress detection

PINguin *penguin*	MONster *monster*	Same | Different (same)
SERvice *service*	jarGON *jargon*	Same | Different (different)

B) Statement/Question differentiation

De gestolen fiets werd in Engeland gevonden. (lowered pitch in the end) *The stolen bike was found in England*	Question | Statement (statement)
De gestolen fiets werd in Engeland gevonden? (raised pitch in the end) *The stolen bike was found in England?*	Question | Statement (question)

C) Contrastive stress detection

<table>
<tr><td>De miljonair liet een huis na aan een neef.
The millionaire bequeathed a house to a cousin</td><td rowspan="3">Wie liet een huis na aan een neef? | Wat liet de miljonair na aan een neef? | Aan wie liet de miljonair een huis na?
Who bequeathed a house to a cousin?| What did the millionaire bequeath to a cousin? | Whom did the millionaire bequeath a house</td><td>(Who bequeathed a house to a cousin?)</td></tr>
<tr><td>De miljonair liet een huis na aan een neef
The millionaire bequeathed a house to a cousin</td><td>(What did the millionaire bequeath to a cousin?)</td></tr>
<tr><td>De miljonair liet een huis na aan een neef
The millionaire bequeathed a house to a cousin</td><td>(Whom did the millionaire bequeath a house?)</td></tr>
</table>

D) Affective prosody

<table>
<tr><td>Een postzegel plak je op een brief
A stamp is attached to a letter</td><td rowspan="2">Angry | sad | happy | Disgust |Don’t know</td><td rowspan="2">(Angry/Sad/Happy/ Disgust/Don’t know)</td></tr>
<tr><td>Een week bestaat uit 7 dagen
A week has seven days</td></tr>
</table>

errors). Compared to the control group, “Angry” and “sad” items were more frequently rated as “disgust” or “Don’t know” in both patients’ groups.

4.2. Pre–post-operative comparison in patients

After resection, the AAT measures, the syntactic comprehension tests and the prosody tests did not differ from the pre-operative scores (Tables 3–5). So, for each of the separate measures there were no significant main effects for time. Although the post-operative patient scores were within normal limits on the AAT, and there was no significant main effect of patient group or time, there was a significant time x group interaction for the naming measure of the AAT ($F(1, 29) = 6.5$; $p < .05$). The item-by-item analysis of the affective prosody test showed group differences for the same four items as pre-operatively, indicating that this pre-operative difference was not affected by surgery.

Table 3
AAT subtests

	Maximum score	Mean (S.D.)				
		Normal controls[a] ($n = 30$)	Dominant		Non-dominant	
			Pre-operative ($n = 16$)	Post-operative ($n = 16$)	Pre-operative ($n = 16$)	Post-operative ($n = 15$)
Spontaneous speech						
Communicative behavior	5	5.0 (0.0)	5.0 (0.0)	5.0 (0.0)	5.0 (0.0)	5.0 (0.0)
Articulation and prosody	5	5.0 (0.0)	5.0 (0.0)	5.0 (0.0)	5.0 (0.0)	5.0 (0.0)
Automated language	5	4.9 (0.4)	5.0 (0.0)	5.0 (0.0)	5.0 (0.0)	5.0 (0.0)
Semantic structure	5	4.9 (0.3)	4.9 (0.3)	4.9 (0.3)	5.0 (0.0)	5.0 (0.0)
Phonematic structure	5	4.8 (0.4)	5.0 (0.0)	5.0 (0.0)	5.0 (0.0)	5.0 (0.0)
Syntactic structure	5	4.8 (0.4)	5.0 (0.0)	5.0 (0.0)	4.9 (0.3)	4.9 (0.3)
Token Test	50	49.1 (1.0)	49 (1.4)	48.2 (2.2)	49.4 (0.9)	49.7 (0.7)
Repeating	150	148.3 (1.8)	148.8 (1.0)	148.3 (2.3)	148.3 (2.0)	149.1 (1.3)
Written language	90	88.8 (1.4)	89.4 (0.8)	89.0 (1.2)	88.6 (1.6)	89.0 (1.4)
Naming[**]	120	115.2 (2.6)	114.1 (4.2)	111.9 (6.1)	116.8 (2.1)	117.6 (1.9)
Comprehension	120	115.0 (3.6)	114.7 (3.3)	114.1 (5.0)	112.5 (6.0)	114.0 (6.2)

[a] Huber et al. (1983).
[**] Significant Group × Time interaction: $F(1, 29) = 6.5$; $p < .05$.

5. Discussion

We compared 32 temporal lobe epilepsy patients and 47 healthy controls on specific tasks of syntactic comprehension and prosodic comprehension before surgery had taken place. TLE patients did not differ from healthy controls in tasks of syntactic comprehension, a task that e.g. Broca's aphasia patients show impairment on (ter Keurs et al., 1999; Wassenaar et al.,

Table 4
Syntactic comprehension test

		Maximum score	Mean (S.D.)				
			Normal controls[a] ($n = 12$)	Dominant		Non-dominant	
				Pre-operative $n = 16$	Post-operative $n = 16$	Pre-operative $n = 16$	Post-operative $n = 15$
Type of sentence		144	138.2 (7.3)	136.9 (7.4)	137.5 (8.1)	137.2 (4.5)	137.8 (7.6)
I	Active, semantically irreversible sentences	24	23.8 (0.4)	23.3 (0.8)	22.9 (1.1)	22.9 (1.3)	22.8 (0.9)
II	Active, semantically reversible sentences	24	23.9 (0.4)	23.7 (0.7)	23.8 (0.8)	23.7 (0.6)	23.7 (1.0)
III	Simple passive sentences	48	46.7 (0.7)	46.3 (2.9)	46 (3.5)	46.1 (1.6)	46.8 (1.8)
IV	Sentences with an active subject-relative clause	24	22.9 (1.7)	22.5 (1.7)	23.2 (1.3)	22.8 (1.3)	22.9 (1.3)
V	Sentences with a passive subject-relative clause	24	20.9 (4.1)	21.2 (2.9)	21.5 (3.2)	21.6 (2.4)	21.5 (4.4)

Absolute scores for five different sentence types: (I) active, semantically irreversible sentences; (II) active, semantically reversible sentences; (III) simple passive sentences; (IV) sentences with an active subject-relative clause; and (V) sentences with a passive subject-relative clause. The syntactic complexity of the sentences increases from II to V.
[a] Wassenaar et al. (2004).

Table 5
Prosody measures

	Total no. of items	Mean (S.D.)				
		Normal controls ($n = 47$)	Dominant		Non-dominant	
			Pre-operative ($n = 16$)	Post-operative ($n = 16$)	Pre-operative ($n = 16$)	Post-operative ($n = 15$)
Word stress detection	20	5.2 (4.2)	6.0 (2.9)	6.3 (6.3)	6.5 (3.1)	7.3 (3.6)
Question–statement differentiation	40	1.1 (2.5)	0.4 (1.3)	0.9 (0.9)	1.1 (3.5)	1.6 (4.4)
Contrastive stress detection	28	4.7 (5.7)	6.1 (6.1)	7.6 (6.1)	6.9 (6.2)	7.8 (5.4)
Affective prosody[*]	28	7.9 (3.2)	10.9 (3.4)	9.9 (4.0)	11.6 (3.4)	11.7 (3.8)

For each test, the absolute number of errors was analysed.
[*] Significant pre-operative difference between patient group and control group: $F_1(2, 76) = 10.1$; $p < .001$; $F_2(2, 54) = 13.8$; $p < .001$. Post hoc tests showed no difference between the dominant and non-dominant patient group. There is no difference between pre- and post-operative performance.

2004). Linguistic prosody comprehension was unaffected as well, but the patients did make more errors in the affective prosody task, regardless of which hemisphere was affected by the illness. Impaired affective prosodic processing may be due to temporal lobe epilepsy-associated damage to mesial temporal lobe structures. There is evidence for impaired recognition of fear and anger in voices or in speech associated with bilateral mesial temporal lobe damage (notably the amygdala) (Scott et al., 1997). Two other studies, however, did not show impairment of recognition of affective prosody in bilateral and unilateral amygdala damaged patients (Adolphs & Tranel, 1999) or in temporal lobectomy patients (Adolphs, Tranel, & Damasio, 2001). An alternative explanation that has been proposed is that affective prosodic processing may be impaired due to effects of anti-epileptic medication on affect (Selai, Bannister, & Trimble, 2005).

We assessed syntactic and prosodic comprehension in the temporal lobe epilepsy patients after neurosurgical removal of the anterior temporal cortex and found no difference compared to presurgical testing, regardless of whether resection involved the dominant or the non-dominant hemisphere. This finding does not support a critical role of the anterior temporal cortex in syntactic or prosodic processing in these patients. We found a differential effect of dominance on anterior temporal lobe resection in confrontation naming of the aphasia battery, where only lesioning the dominant side (left temporal lobe) caused a small decrease in performance, whereas naming after lesioning the non-dominant (right) side remained normal. Naming thus seems the most sensitive language measure of an lesion in the dominant hemisphere. (Bell & Davies, 1998; Falconer, 1958; Lu et al., 2002; Saykin et al., 1995; Strauss et al., 2000). This effect did not bear relevance to comprehension given the absence of clear effects of surgery on the other tests.

Negative findings require due deliberation on alternative explanations. One could argue that our tests may not have been sensitive enough to detect deficits in the patients. However, given that the syntactic tasks were designed to detect deficits associated with aphasia, missed deficits would likely be quite small. Hence, we can reasonable state there were no deficits of noticeable significance. There are several possible explanations of a more conceptual nature for the observation that removal of the anterior temporal cortex did not significantly change comprehension performance.

Firstly the resection might have been insufficient to damage the presumed language-related areas in the anterior temporal lobe. In functional imaging studies reporting anterior temporal lobe activity in association with either syntax or prosody, the active areas were found in the most anterior tip of the temporal lobe, i.e. the temporal pole (Brodmann area 38) (Crinion et al., 2003; Humphries et al., 2001, 2005; Mazoyer et al., 1993), which is certainly within the resection area of the present study. An anterior temporal lobe area that has been suggested to be involved in syntactic processing on the basis of a lesion overlap study on agrammatic aphasics (Dronkers, Wilkins, Van Valin, Redfern, & Jaeger, 1996) is referred to as the anterior part of Brodmann area 22. Compared to the probability map for the primary auditory cortex provided by Penhune, Zatorre, MacDonald, and Evans (1996) this suggested syntax-related area would be within the resection borders of the present study. In a later paper (Dronkers, Wilkins, Van Valin, Redfern, & Jaeger, 2004), the authors emphasized that the area implicated in syntactic processing is at least 6 cm from the temporal pole and thus is not resected in patients undergoing left anterior temporal lobectomy. Note, however, that in this study the most posterior Talairach coordinates for the overlap in Brodmann area 22 are given as $y = -19.4$ mm. Given that the tip of the temporal lobe is at $y = +25$ mm (Talairach & Tournoux, 1988), this means that the major part of the overlap area is less than 4.5 cm from the tip of the temporal lobe and therefore falls within the resection borders of the present study. In sum, the resected part of the anterior temporal lobe clearly encompasses neural tissue that has been linked to processing of syntax and prosody in both lesion and functional imaging studies. It is therefore unlikely that the resected area was too small to include the postulated neural correlate of these language functions in the anterior temporal lobe.

Second, reorganization of language functions might account for our negative findings. Although reorganization can take place *after* the surgical removal of the anterior temporal cortex (Pataraia et al., 2005), we assessed patients within 8 weeks after surgery, and post-lesion reorganization of language generally takes considerably longer (Price & Crinion, 2005). There also may have been reorganization of language functions *before* surgery. The patients in this study suffered from epilepsy for some time, and epilepsy-induced changes in functional brain anatomy may have lead to a reorganization of syntactic and prosodic comprehension functions. Based on the pre-operative Wada testing, a reallocation of language functions that are necessary for syntactic and prosodic comprehension to homologous areas of the right hemisphere seems unlikely, because no impairment of language functions after injection of amobarbital sodium into the right cerebral artery was observed for the left dominant patients. Still, the Wada procedure does not specifically test for syntactic and prosodic comprehension skills, so it remains a theoretical possibility.

Imaging studies have suggested that activity patterns may be altered. In pre-operative functional imaging studies on language in TLE patients, left TLE patients have been shown to be less lateralized compared to controls, possibly due to an increase of activity in the right frontal regions (Adcock, Wise, Oxbury, Oxbury, & Matthews, 2003; Gaillard et al., 2002; Voets et al., 2006). This may however not be due to illness-induced depletion of language activity in the temporal poles, because activity is frequently observed in this region in these patients during performance of sentence reading (e.g. Powell et al., 2007; Rutten et al., 2002) which does not significantly differ from healthy controls (Powell et al., 2007). It suggests that, like healthy controls, patients do activate both temporal poles in sentence comprehension.

Given the age of epilepsy onset and the (Verbal) IQ our group of patients probably had normal language development (Schwartz, Devinsky, Doyle, & Perrine, 1998). However, we cannot rule out a pre-operative reorganization of language functions to more posterior areas of the left temporal lobe. This could be investigated by means of pre- and postsurgical functional neuroimaging.

A third, and in our view most plausible, explanation is that the part of the anterior temporal cortex that is removed in anterior temporal lobectomy is not a critical area for syntactic and prosodic comprehension, even in healthy subjects. The left anterior temporal cortex may be involved in syntactic and prosodic processing but other brain areas may sufficiently support these functions as well, such that the involvement of the left anterior temporal lobe is not essential. For example, damage of *both* anterior temporal cortices might be necessary to produce impaired syntactic and/or prosodic comprehension. An interesting finding in this regard is that in left TLE patients the right temporal pole exhibits activity after surgery during a reading comprehension test (Noppeney et al., 2005), thereby perhaps sustaining performance, which would support the notion of bilateral representation.

In this study we assessed effects of anterior temporal lobe resection on sentence comprehension using state of the art psycholinguistic tests in a moderately large sample of epilepsy patients. We found no significant effect of surgery on performance on tasks that require syntactic or prosodic processing, even if the resection was performed in the language-dominant hemisphere. This finding implies that resection of the anterior temporal lobe does not cause permanent loss of language comprehension functions, or at least not enough to be noticed with psycholinguistic tests. We take these results to suggest that sentence comprehension, or, syntactic and prosodic processing may not critically depend on integrity of the temporal pole. Given that absence of effects (null results) does not constitute definite evidence for absence of the targeted functions in temporal pole, further studies are required to rule out alternative explanations such as pre- or postsurgical reorganization, in which functional neuroimaging could be informative.

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