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Patterns of comprehension performance in agrammatic Broca's aphasia: A test of the Trace Deletion Hypothesis

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Abstract

We tested the core prediction of the Trace Deletion Hypothesis (TDH) of agrammatic Broca's aphasia, which contends that such patients' comprehension performance is normal for active reversible sentences but at chance level for passive reversible sentences. We analyzed the comprehension performance of 38 Italian Broca's aphasics with verified damage to Broca's area, who completed sentence-to-picture matching tasks using active and passive reversible sentences as stimuli. The results failed to confirm the predictions made by TDH: only a small minority (15%) performed at chance on passive sentences and better than chance on active sentences. Furthermore, the distribution of the 38 subjects' performance on passive sentences differed from that predicted by the TDH since many more subjects performed at better-than-chance levels than expected. We discuss the implication of these results for claims about the distribution of language processing mechanisms in the brain.

Keywords: Agrammatism; Comprehension deficit; Left inferior prefrontal cortex; Broca's aphasia

1. Introduction

Is agrammatic Broca's aphasia associated with a specific comprehension performance profile? This question has been one of the central foci of investigation in aphasia research, at least since Caramazza and Zurif (1976) first showed that a group of Broca's aphasics performed poorly in a sentence comprehension task with semantically reversible sentences—sentences that require correct syntactic analysis for good performance. Caramazza and Zurif's observation received ample confirmation in subsequent studies (e.g., Caramazza, Berndt, Basili, & Koller, 1981; Goodglass et al., 1979; Heilman & Scholes, 1976; Schwartz, Saffran, & Marin, 1980) leading to the proposal that Broca's aphasia reflects a deficit of syntactic processing and that, therefore, Broca's area is importantly implicated in syntactic analysis (see also Caramazza & Berndt, 1978; Caramazza & Zurif, 1976). However, it has since become apparent that not all Broca's aphasics present with asyntactic comprehension (the failure to understand semantically reversible sentences; Bastiaanse, 1995; Caramazza & Hillis, 1989; Kolk, Van Grunsven, & Keyser, 1985; Laine, Niemi, Niemi, & Koivuselka-Sällinen, 1990; Miceli, Mazzucchi, Menn, & Goodglass, 1983; Nespoulous et al., 1988), and that not all subjects with asyntactic comprehension also present with agrammatic production (e.g., Caramazza & Miceli, 1991; Martin & Blossom-Stach, 1986).

The reported dissociation between agrammatic speech and asyntactic comprehension is clearly problematic for the hypothesis that both deficits are caused by damage to a common syntactic processing mechanism

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implicating Broca's area. The reaction to this state of affairs has not been uniform. Some researchers interpreted the dissociation as indicating that the complex performance of Broca's aphasics reflects the contribution of damage to neurally adjacent but functionally independent mechanisms involved in language production and comprehension (e.g., Caramazza & Berndt, 1985; Goodglass & Menn, 1985), which are often damaged together because of their neural proximity but on occasion can be affected selectively, resulting in the observed dissociations. Other researchers, while acknowledging the existence of the apparently problematic cases, did not deem those results sufficiently clear-cut to abandon the view that agrammatic production and asyntactic comprehension result from a common cause and that, therefore, must be impaired or spared together (e.g., Grodzinsky, 2000; Zurif, 1996). But, what could motivate such a position?

In a recent paper, Grodzinsky, Piñango, Zurif, and Drai (1999) provided a justification for dismissing the recalcitrant results for the unitary deficit hypothesis of Broca's aphasia. They argued that those data came from single-case studies and therefore their interpretation is uncertain unless considered in the broader context of all other relevant cases of agrammatic Broca's aphasia. Specifically, they argued that the recalcitrant case reports merely represent outliers in a normally distributed pattern of results that conform with the predictions derived from their theory of agrammatic Broca's aphasia.[1] This theory attributes agrammatic patients' comprehension failure to an inability to co-index phonological traces, denoting moved constituents (the so-called Trace Deletion Hypothesis—TDH), because of damage to such traces.

According to this theory, under normal conditions understanding a passive sentence like *The boy is kissed by the girl* relies on the correct processing of phonological traces. In the example, *The boy*$_i$ *is kissed* $\boldsymbol{t}_i$ *by the girl* contains a trace ($\boldsymbol{t}_i$) that signals the movement of the noun phrase *The boy*, corresponding to the theme role in the thematic grid of the verb, to the subject position. Intact ability to process the trace is crucial for understanding the sentence, since it provides the strongest cue for assigning the subject (hence, the theme) role to the correct noun phrase. If the trace were somehow unavailable (because of brain damage), the unambiguous assignment of thematic roles would be impossible. Under these pathological circumstances, the agent role would be assigned both to the first noun, on the basis of order information, and to the second noun, on the basis of information about passive morphology (the—*by* phrase). Faced with such conflicting information, the agrammatic subject has little choice but to randomly assign the agent role to the first or to the second noun. However, performance on actives would be good because in these sentences linear order and hierarchical structure converge in assigning the agent role to the first noun of the sentence (the subject). Thus, this account predicts that Broca's aphasics should comprehend active, reversible sentences normally, and perform at random on passive, reversible sentences. Grodzinsky et al. (1999) further argue that their theory predicts that in agrammatic Broca's aphasics *taken as a group*, comprehension of passive reversible sentences should be at chance *on average*, but individual scores should be distributed in a gaussian curve—most subjects scoring at chance levels, and others reaching scores more or less distant from the mean, in both directions.

To support this proposal, Grodzinsky et al. (1999) produced a meta-analysis of approximately 40 published cases of agrammatic Broca's aphasia, all of whom completed testing of sentence comprehension with varying numbers of active and passive reversible sentences. The average performance of these subjects taken as a group was better than chance on reversible actives, was indistinguishable from chance on reversible passives, and was significantly more accurate for actives than for passives. The methodological approach to the analysis of comprehension performance used by Grodzinsky and collaborators has been criticized by several authors (Berndt & Caramazza, 1999; Caplan, 2001; Caramazza et al., 2001). Caramazza et al. (2001), for example, analyzed the same database used by Grodzinsky et al. but reached the opposite conclusion (see also Berndt, Mitchum, & Haendiges, 1996). They conducted an individual subject analysis of the comprehension results, and calculated for each subject the probability that the observed performance deviated to a statistically significant extent from the expected chance distribution. Their analysis showed that the profile predicted by Grodzinsky et al. (1999), that is, good performance on actives and chance performance on passives, was only one, and not even the most frequent, of the patterns of performance observed in the sample considered in the meta-analysis. Similarly heterogeneous results were obtained in a study on the comprehension of active and passive reversible sentences by Luzzatti, Toraldo, Ghirardi, Lorenzi, and Guarnaschelli (2001). The conclusion reached by Caramazza et al. (2001) was that, even if one accepted the logic of Grodzinsky et al.'s claim (but see Footnote 1), the pattern of performance of the subjects entered in the meta-analysis did not fall in a normal distribution—outliers were far too numerous, and their error distribution patterns violated the expectations of a normal distribution. This outcome is inconsistent with the view of a common

[1] Here we leave aside the fact that this argument is specious. As we have argued elsewhere (Caramazza, Capitani, Rey, & Berndt, 2001; see also Caplan, 2001), when properly analyzed the investigation of individual cases explicitly considers the probability that the patient's performance deviates from a theoretically expected value (in this case, chance level).

deficit underlying both agrammatic speech and agrammatic comprehension in Broca's aphasia, and suggests that these subjects suffer from heterogeneous linguistic and cognitive deficits.

Although Caramazza et al.'s reanalysis of the data considered by Grodzinsky et al. (1999) undermines the latter authors' claim that when individual case reports are considered in the broader context of other reported cases they are consistent with the TDH and against the multi-component view of Broca's aphasia, the data themselves are difficult to evaluate, as is frequently the case with meta-analyses. One problem is practical in nature, and concerns the database considered for the analysis. As is always the case with retrospective studies, the subjects included in the meta-analysis were tested in different laboratories, in different languages, on tasks that included different verbal and pictorial materials, different numbers of stimuli, etc. In some cases the number of stimuli used with each patient was so small as to make meaningful statistical analysis impossible. These factors could have introduced noise in the data, making the interpretation of the results difficult. Another problem is potentially more troublesome, and relates to subject selection. In a meta-analysis, only published cases are considered, and the latter may not reflect the actual distribution of the phenomena under consideration. Researchers tend to publish case studies that are more likely to support or disprove a theoretical proposal, and typically they are based on the most "extreme" outcomes. Furthermore, the editorial process favors positive results making it less likely that failures to find an effect would find their way into the literature. This practice tends to favor the publication of results that show the theoretically expected pattern. Consequently, a simple count of the published cases could give a distorted view of the relevant performance patterns, and prevent a real understanding of their natural rate of occurrence.

An additional issue raised by the reported meta-analyses relates to the fact that the TDH is not only a functional claim about the linguistic deficit affecting subjects who are clinically classified as agrammatic Broca's aphasics, but also a neuroanatomical claim about the role of Broca's area. Specifically, the claim is that Broca's area provides the neural substrate for the coindexation of traces. To be included in the meta-analysis, subjects had to have been clinically diagnosed as agrammatic Broca's aphasics, and their comprehension had to have been evaluated by means of active and passive reversible sentences, presented in the context of stimulus-picture matching tasks, in which a sentence was matched to one of two pictures—the correct target and a foil. However, verified damage to Broca's area was not always a criterion for inclusion—it was simply assumed that if the patient presented with Broca's aphasia he/she had sustained damage to Broca's area. Since the sample selected for the meta-analysis might have included cases with damage to disparate brain structures, it is not clear how forcefully those data speak to the relationship between the left inferior prefrontal gyrus and the co-indexation of traces.

For all these reasons, we thought it reasonable to re-evaluate the comprehension profile in agrammatic Broca's aphasia. Our investigation focuses on a series of 38 consecutive subjects clinically diagnosed as agrammatic Broca's aphasics, all presenting with verified neuroradiological (CT or MRI) damage to Broca's area. The patients completed the same tasks, requiring the comprehension of active and passive reversible sentences.

2. Subjects

The subjects reported on in this manuscript were selected from a sample of over 200 consecutive aphasics, referred to the Neuropsychology Service of the Catholic University (Rome) between the years 1991 and 2000, who completed the BADA (Batteria per l'Analisi dei Deficit Afasici), a 36-task battery for the assessment of aphasic disorders (Miceli, Laudanna, Burani, & Capasso, 1994). These subjects are only a subgroup of the aphasic subjects seen in the Service during the same period of time. Since a significant component of the BADA involves reading and writing tasks, it is administered only to subjects with at least 8 years of formal education. To avoid unnecessary frustration, subjects with less than 8 years of schooling are usually asked to complete a shorter screener. Exceptions are made for subjects with 5–7 years of schooling, whose personal and occupational histories indicate a level of reading and writing skills superior to that expected on the basis of their formal education. Two subjects of this type were included in our experimental group. Italian was the native language of all the subjects included in the study.

From the original pool of 200 aphasics, we selected those who met two core criteria for classification as agrammatic Broca's aphasics—patients whose performance could be used to evaluate the TDH. The first criterion was non-fluent, agrammatic speech. Relevant information on a subject's spoken output was obtained from two spontaneous narratives (history of illness and daily activities) and from two picture description tasks, each consisting of 10 stimuli. In one task, production was unconstrained; in the other task, production was constrained so as to induce the subject to produce active and passive sentences. Fluency was measured as the average number of words produced by the subject in 1 min in the spontaneous narratives. Subjects were considered to be agrammatic if they had difficulty with free-standing and bound grammatical morphemes and produced short utterances, characterized by simplification of grammatical structure. Their production deficit was rated as "mild," "moderate" or "severe" agrammatism, based on a clinical evaluation by two of us (RC and GM), who independently assessed the spontaneous speech sample collected from each subject. In case of contrasting conclusions, the rating was assigned by agreement. In most subjects, varying degrees of dysarthria and dysprosodia were also present.

The second criterion for inclusion was unilateral anatomical damage to the frontal lobe, ascertained by means of CT-scan or MRI-scan. Damage in all subjects involved areas BA 44 and 45, but in essentially all cases the lesion was larger and also affected the deep white matter of the frontal (and often also parietal or temporal) lobe.

As a consequence of this procedure, 38 subjects were selected. There were 25 males and 13 females; premorbibly, 36 were right-handers suffering from lesions in the left hemisphere, and 2 were left-handers (SVE was a corrected left-hander) with a right hemisphere lesion. The latter two cases were included because on clinical testing and on the BADA they presented with all the typical features of Broca's aphasia. The essential biographical and lesion information on these subjects is presented in Table 1, along with a schematic report on their speech disorder.

3. Materials

The ability to process traces was evaluated through performance in the auditory and the visual sentence comprehension subtests of the BADA. Both tasks used simple declarative sentences as stimuli. In the auditory task ($n = 60$ stimuli), the sentence was pronounced by the examiner; in the visual task ($n = 45$ stimuli) it was shown to the subject, written on a card. In both cases, the subject was asked to match the stimulus sentence to one of two pictures. Half of the stimuli were presented in the active voice, half in the passive voice. Active sentences were of the SVO type (*Il ragazzo abbraccia la ragazza*, The boy hugs the girl); passive sentences were also presented in the canonical word order—Subject NP/Verb/By-phrase (*La ragazza è abbracciata dal ragazzo*, The girl is hugged by the boy). In Italian, passive sentences behave just like passive sentences in English, with one exception, namely that the past participle behaves like an adjective, and agrees in number and gender with the grammatical subject (thus, *La ragazza è abbracciat a dal ragazzo*, The girl is hugged$_{\text{f.sg.}}$ by the boy, and *Le ragazze sono abbracciat e dal ragazzo*, The girls are hugged$_{\text{f.pl.}}$ by the boy). In each trial, one of the two alternatives always represented the correct choice; the other represented a role reversal foil, a morphological foil or a lexical-semantic foil. Role reversal trials were constructed as follows: a sentence like *Il ragazzo è abbracciato dalla ragazza*, The boy is hugged by the girl, was paired with two pictures, one representing the correct action, the other a boy hugging a girl (this alternative action would be described as either *La ragazza è abbracciata dal ragazzo*, The girl is hugged$_{\text{f.sg.}}$ by the boy, or *Il ragazzo abbraccia la ragazza*, The boy hugs the girl). For trials with morphological foils, a sentence was presented with the correct target and with an alternative representing either the first or the second noun in a different number for example, two boys being hugged by a girl, or two girls hugging a boy, corresponding to *I ragazzi sono abbracciati dalla ragazza*, The boys are hugged$_{\text{m.pl.}}$ by the girl, and to *Il ragazzo è abbracciato dalle ragazze*, The boy is hugged$_{\text{m.sg.}}$ by the girls, respectively. The inflectional morphology of the first and of the second noun was varied an equal number of times. For trials that evaluated the subjects' sensitivity to lexical-semantic foils, a sentence was paired with an alternative that represented a semantically related noun (two-thirds of the time—the first and the second noun were modified an equal number of times), or a semantically related action (one-third of the time). For example, the alternative to the picture of a boy being hugged by a girl (*Il ragazzo è abbracciato dalla ragazza*) would represent a grandfather being hugged by a girl (*Il nonno è abbracciato dalla ragazza*), or a boy being hugged by a grandmother (*Il ragazzo è abbracciato dalla nonna*), or a boy being pushed by a girl (*Il ragazzo è spinto dalla ragazza*). Each of the three foil types (role reversal, morphological, and lexical-semantic) occurred 20 times in the auditory task, and 15 times in the visual task. The auditory task included 30 sentences in the active voice, and 30 in the passive voice (10 active sentences and 10 passive sentences for each foil type). The visual task included 23 sentences in the active voice, 22 in the passive voice (7 active and 8 passive sentences for the role reversal foil, 8 active and 7 passive sentences for the morphological and the same number for the lexical foil). Both tasks were administered without time constraints. In the auditory task, the stimulus sentence could be presented twice if request by the subject. The last response produced by the subject was retained for scoring.

Thirty-six out of 38 subjects completed both the auditory and the visual task. Subjects DFU and LPA completed only the auditory task. Subjects FBIN, GDM, MPA, VPI, and GSI completed the auditory and the visual tasks twice, on separate occasions; and subjects DBO and RPA completed both tests three times, also at different times. Since accuracy levels on the auditory and the visual task were comparable in each subject, only the overall score is considered for each participant (that is, the sum total of correct responses to auditory and to visual sentence–picture matching). In addition, since the subjects who completed the tasks more than once performed with comparable accuracy in all sessions (this was true both for the overall error rate, and for the distribution of incorrect responses to the various foil types), results were also collapsed across administrations.

Table 1
Biographical and lesion information, and main features of the spontaneous speech of the 38 agrammatic participants

N	Init	Etiol	Les. site	Sex	Age	Hnd	Edu	Dysartria	Fluency	Agram
1	MBA	L ICVA	FPT	M	53	R	8	1	3	3
2	RPE	L ICVA	FP	M	48	R	13	2	3	3
3	CCP	L AVM	FPT	F	36	R	13	1	2	2
4	FBI	L ICVA	FPT	M	49	R	17	3	3	3
5	FAU	L ICVA	F	M	47	R	13	1	3	3
6	OGA	L ICVA	FT	M	55	R	8	2	3	3
7	SVE	R ICVA	FTP	M	69	L	17	2	2	2
8	TGU	L HCVA	FTP	F	41	R	11	2	3	3
9	FAL	L ICVA	FTP	M	44	R	8	2	2	2
10	LCA	L ICVA	FPT	F	46	R	13	0	1	2
11	LDO	L ICVA	FT	M	70	R	17	2	2	3
12	GDM	L ICVA	FT	M	59	R	13	0	1	1
13	CDS	L ICVA	FPT	F	63	R	8	1	2	2
14	DBO	L ICVA	FTP	M	43	R	17	2	3	3
15	FBI	L ICVA	FP	M	59	R	13	2	2	2
16	LPA	L ICVA	F	F	65	R	5	2	3	1
17	VPI	L ICVA	F	F	44	R	13	2	3	2
18	MPA	L ICVA	F	F	29	R	13	1	1	1
19	FMA	L ICVA	FTO	M	65	R	13	0	2	1
20	RRO	L trauma	F	F	20	R	13	2	3	3
21	RBO	L AVM	FTP	F	38	R	11	1	2	2
22	DFU	L ICVA	FTP	M	52	R	13	2	2	2
23	SCU	L ICVA	FP	M	59	R	13	1	2	2
24	VPI	L HCVA	Basal G	M	59	R	17	1	2	2
25	FCA	L ICVA	F	M	43	R	13	2	3	2
26	AMO	L ICVA	FPT	M	54	R	8	2	3	3
27	RMO	L HCVA	FT	M	42	R	17	1	1	3
28	CZA	L ICVA	FP	F	28	R	8	2	3	2
29	DFE	L ICVA	FTP	F	49	R	17	2	2	3
30	LAN	L ICVA	FTP	F	59	R	17	2	2	3
31	GSI	L ICVA	FP	M	59	R	17	1	1	1
32	VTO	L ICVA	FPT	F	62	R	5	0	1	1
33	CAN	L AVM	F	M	32	R	13	0	0	1
34	MCI	L ICVA	FP	M	59	R	13	0	1	1
35	AFO	L ICVA	FP	F	56	R	13	0	1	1
36	FVE	R HCVA	FP	M	46	R	17	1	1	1
37	GMU	L HCVA	FPT	M	47	R	17	1	1	1
38	RPA	L trauma	L/FP	M	40	L	17	1	1	1

Dysartria: 0, no dysartria; 1, mild; 2, moderate; and 3, severe. Fluency: 0, fluent; 1, mild dysfluency; 2, moderate dysfluency; and 3, severe dysfluency; and Agrammatism: 1, mild[a]; 2, medium[b]; and 3, severe[c]. Severity of agrammatism was scored clinically, based on the presence of one or more of the following:

[a] Some omissions of free-standing grammatical words; some agreement errors; at least some subordination present in spontaneous speech.

[b] Frequent omissions of free-standing grammatical words; frequent agreement errors; marked tendency to produce verbs in non-finite forms; substantial simplification of syntactic structure.

[c] Almost systematic omission of free-standing grammatical words; verbs produced almost systematically in one of the non-finite forms, or in a "stereotyped" finite form (e.g., most verbs in the 3rd singular, present indicative, regardless of context); extreme simplification of syntactic structure (speech reduced to isolated nouns or verbs, or to noun–verb or verb–noun sequences).

Since we were interested in evaluating whether or not the TDH provides a viable account of the comprehension disorder observed in Broca's aphasics, only performance on sentences presented with a role reversal foil was considered. Thus, the analyses that follow focus on the responses produced to 20 sentences (10 actives, 10 passives) by subjects DFU and LPA; to 70 sentences (36 actives and 34 passives) by FBI, GDM, MPI, VPI, and GSI; to 105 sentences (54 actives, 51 passives) by DBO and RPA; and to 35 sentences (18 actives and 17 passives) by the remaining 29 subjects.

4. Statistical methods

The statistical analysis of the data was tailored to test three predictions made by the TDH. The hypothesis predicts that performance on active reversible sentences should be significantly more accurate than performance on passive sentences. To evaluate this possibility, we checked for each subject if the hit rate was higher for actives than for passives. The comparison was carried out with Fisher's exact test, adopting a one-sided .05 significance level for each subject, without Bonferroni correction. This criterion tends to inflate the number of significant comparisons and favors the outcome expected by the TDH.

The TDH predicts that comprehension of active sentences should be better than chance (chance corresponding in this case to a .500 hit rate), whereas comprehension of passive sentences should be at chance. To assess this prediction of the theory, we calculated for each subject the .05 confidence limits of the observed hits for reversible active sentences and reversible passive sentences. The confidence limits of the observed performance should include chance for passive but not for active sentences.

Finally, to see whether the comprehension profiles of the subjects included in this study were distributed along a Gaussian distribution, we analyzed the general performance profile of the group by transforming the observed binomial data into z points, and by checking whether the resulting z points significantly diverged from the normal distribution. In this case, the z value was calculated following the same procedure used by Caramazza et al. (2001).

5. Results

The raw percentage of correct responses produced by each subject in the study is reported in Table 2, in which subjects are ordered from most to least impaired. The table displays overall correct responses (collapsing across foil types), correct responses to sentences presented with a role reversal foil, and a breakdown of these responses for sentences presented in the active voice and in the passive voice, respectively. As it can be seen, there

Table 2
Number of incorrect responses produced by agrammatic speakers on the Sentence Comprehension Task (results for multiple administrations were collapsed)

N	Patient	Total	%	Rev	Mor	Sem	R-a	R-p
1	MBA	31/105	29.5	17/35	6/35	8/35	4/18	13/17
2	RPE	30/105	28.6	19/35	4/35	7/35	7/18	12/17
3	CCP	29/105	27.6	15/35	6/35	8/35	5/18	10/17
4	FBI	28/105	26.7	14/35	9/35	5/35	7/18	7/17
5	FAU	27/105	25.7	14/35	8/35	5/35	7/18	7/17
6	OGA	27/105	25.7	14/35	3/35	10/35	7/18	7/17
7	SVE	27/105	25.7	13/35	8/35	6/35	6/18	7/17
8	TGU	26/105	24.8	12/35	11/35	3/35	5/18	7/17
9	FAL	25/105	23.8	19/35	2/35	4/35	8/18	11/17
10	LCA	25/105	23.8	15/35	3/35	7/35	6/18	9/17
11	LDO	24/105	22.9	15/35	2/35	7/35	9/18	6/17
12	GDM	46/210	21.9	14/70	17/70	15/70	5/36	9/34
13	CDS	23/105	21.9	17/35	2/35	4/35	9/18	8/17
14	DBO	66/315	21.0	50/105	9/105	7/105	24/54	26/51
15	FBI	43/210	20.5	18/70	12/70	13/70	9/36	9/34
16	LPA	12/60	20.0	6/20	2/20	4/20	3/10	3/10
17	VPI	36/210	17.1	25/70	7/70	4/70	13/36	12/34
18	MPA	35/210	16.7	25/70	5/70	5/70	13/36	12/34
19	FMA	16/105	15.2	7/35	2/35	7/35	3/18	4/17
20	RRO	16/105	15.2	13/35	2/35	1/35	4/18	9/17
21	RBO	16/105	15.2	15/35	1/35	0/35	5/18	9/17
22	DFU	9/60	15.0	4/20	2/20	3/20	1/10	3/10
23	SCU	14/105	13.3	9/35	2/35	3/35	2/18	7/17
24	VPI	14/105	13.3	10/35	2/35	2/35	5/18	5/17
25	FCA	13/105	12.4	9/35	0/35	4/35	2/18	7/17
26	AMO	13/105	12.4	8/35	3/35	2/35	4/18	4/17
27	RMO	11/105	10.5	5/35	4/35	2/35	2/18	3/17
28	CZA	11/105	10.5	7/35	2/35	2/35	2/18	5/17
29	DFE	10/105	9.5	4/35	2/35	4/35	2/18	2/17
30	LAN	7/105	6.7	7/35	0/35	0/35	3/18	4/17
31	GSI	12/210	5.7	4/70	2/70	6/70	2/36	2/34
32	VTO	5/105	4.8	2/35	0/35	3/35	1/18	1/17
33	CAN	4/105	3.8	3/35	0/35	1/35	2/18	1/17
34	MCI	4/105	3.8	3/35	0/35	1/35	2/18	1/17
35	AFO	4/105	3.8	3/35	0/35	1/35	2/18	1/17
36	FVE	4/105	3.8	2/35	2/35	0/35	1/18	1/17
37	GMU	3/105	2.9	3/35	0/35	0/35	1/18	2/17
38	RPA	8/315	2.5	6/105	0/105	2/105	1/54	5/51

Total, total number of errors on the Sentence Comprehension task; Rev, Mor, Sem, number of incorrect choices of the role reversal, of the morphological and of the lexical-semantic foil; R-a, R-p, number of incorrect choices of the role reversal foil for active (R-a) and passive (R-p) sentences.

is extensive variability in the sample. When overall response accuracy is considered, error rates ranged between essentially normal levels for RPA (2.5%), GMU (2.9%), CAN, MCI, AFO, and FVE (3.8% each) to very severe impairment for FAU, MBA, FBI, CCP, OGA, RPE, and SVE (around 25%). Accuracy in responding to sentences presented with a role reversal foil also varied substantially across subjects. Error rates were relatively low (5.7%) in GSI, RPA, VTO, and FVE, but very high (40% or greater) in DBO, FAL, FAU, MBA, FBI, CCP, MCI, CDS, LDO, TGU, VPI, and RBO. In addition, error rates for the three stimulus types varied across subjects. In some cases, incorrect responses to stimuli in which the correct response was presented together with a role reversal foil occurred at approximately the same rate as the incorrect responses to stimuli presented with a morphological or a lexical-semantic alternative (e.g., cases GDM and GSI: 30.4 and 33.3%, respectively). In other subjects, incorrect responses overwhelmingly occurred to items in which the picture representing the target sentence was presented with a foil representing the reversal of thematic roles (MPA, VPI, DBO, RPA, FAL, CAN, FCA, MCI, CDS, AFO, VPI, RRO, LAN, GMU, and RBO). No specific overall pattern could be discerned in the subjects' performance on active and passive sentences, collapsing across foil types. The variability in the patterns of comprehension performance of reversible sentences in the 38 aphasics included in our sample suggests that they may have distinct functional disorders.

The main focus of this study, however, is the evaluation of the TDH. For this purpose, the critical comparisons involve our subjects' accuracy in responding to the stimuli that require the correct assignment of thematic roles. In the materials we used, the critical stimuli for this comparison are those in which the subjects had to choose between the picture corresponding to the target sentence and an alternative representing the reversal of thematic roles. The hypothesis advanced by Grodzinsky (2000) makes three straightforward predictions. The first two predictions concern the pattern of performance to be found in each participant: (1) performance should be more accurate on actives than on passives; and (2) it should be at above-chance levels for actives and at chance level for passives. The third prediction concerns the behavior of agrammatic Broca's aphasics as a group: the performance of these subjects on passives is allowed to vary, but should be part of the normal distribution, with mean at 50%. The data relevant for the evaluation of these predictions are presented in Table 3.

The first column in Table 3 shows the statistical comparison between the number of correct responses produced to active and passive reversible sentences, carried out by means of the Fisher exact test. Inspection of the analysis shows that only 3/38 subjects (7.9%) obtained a significantly higher hit rate with active reversible sentences than that with passive reversible sentences (cases MBA, FCA, and SCU). Having adopted one-sided comparisons without Bonferroni adjustments, we are certain that no differences were masked by strong statistical protection.

The second and third columns in Table 3 show whether or not each subject's performance on actives and on passives includes chance level, based on the statistical criteria discussed in Section 4. The TDH predicts that in agrammatic Broca's aphasics, performance on actives should not include the chance level, whereas performance on passives should include it. Inspection of Table 3 shows that this was true for only 6/38 subjects (15%), namely DFU, MBA, FCA, SCU, RRO, and CZA. This analysis is not strictly comparable to a direct comparison between active and passive sentences. Nonetheless, the number of subjects conforming with the predictions of the TDH is quite low.

To evaluate the pattern of performance of the group as a whole, we transformed the proportion of correct responses to the passive sentences for each subject to z scores (Table 3, rightmost column). The reported z scores indicate the normalized distance of the observed proportion of correct passives from the expected rate of .500 (i.e., chance level). The TDH predicts that individual cases might deviate from chance level, but that these individual deviations should be distributed normally around the expected mean of .500 correct (which represents chance level). A diagram presenting the expected and the observed distribution of data from our sample is presented in Fig. 1. Scores in our group of agrammatic Broca's aphasics are definitely skewed toward greater-than-chance values. The comparison was based on 5 intervals by collapsing into a single cell the last four columns of Fig. 1. The contrast between the observed values and the values predicted by TDH yields a χ^2 value of 97.008, with $df = 4$, $p < .0001$ (for a comment on the calculation of degrees of freedom, see Caramazza et al., 2001).

6. Discussion

The aim of the study was to determine whether the sentence comprehension profiles of a group of Italian-speaking agrammatic Broca's aphasics, all with verified damage to Broca's area, could be uniformly ascribed to an inability to process phonological traces. As noted in Section 1, the TDH makes three clear predictions about the comprehension performance of agramamtic Broca's aphasics: (1) comprehension of reversible sentences should be significantly better for active than for passive sentences; (2) comprehension of reversible active sentences should be above chance, while comprehension of reversible passive sentences should be at chance; and (3) comprehension performance for reversible passive

Table 3
Comparison of the percentage of correct responses to active and passive reversible sentences

N	Initials	Reversible: Active vs. Passive Underlined: significant comparisons	Confidence limits of the percentage correct for the Reversible condition. Subjects for which the percentage correct with the passive sentences includes the chance level while the percentage correct of active sentences does not include the chance level are underlined		Proportion of correct passives: the reported z points indicate the normalized distance of the observed proportion of correct passives from the expected rate of .500 (i.e., the chance)
		Hits observed with passives and actives; comparison by means of Fisher's exact test	Passive	Active	Observed proportion and z
1	MBA	4/17 vs. 14/18; $p = .0017$	.235 (.085–.489)	.778 (.535–.920)	4/17−2.185
2	RPE	5/17 vs. 11/18; $p = .0609$	.294 (.124–.544)	.611 (.375–.827)	5/17−1.699
3	CCP	7/17 vs. 13/18; $p = .0646$	.412 (.184–.663)	.722 (.465–.883)	7/17−0.726
4	FBI	10/17 vs. 11/18; $p = .5815$	.588 (.337–.816)	.611 (.375–.827)	10/17 0.726
5	FAU	10/17 vs. 11/18; $p = .5815$	.588 (.337–.816)	.611 (.375–.827)	10/17 0.726
6	OGA	10/17 vs. 11/18; $p = .5815$	.588 (.337–.816)	.611 (.375–.827)	10/17 0.726
7	SVE	10/17 vs. 12/18; $p = .4481$	.588 (.337–.816)	.667 (.410–.844)	10/17 0.726
8	TGU	10/17 vs. 13/18; $p = .3164$	.588 (.337–.816)	.722 (.465–.883)	10/17 0.726
9	FAL	6/17 vs. 10/18; $p = .1943$	.353 (.166–.593)	.555 (.325–.764)	6/17−1.212
10	LCA	8/17 vs. 12/18; $p = .2036$	.471 (.253–.722)	.667 (.410–.884)	8/17−0.242
11	LDO	11/17 vs. 9/18; $p = .2962$	.647 (.406–.834)	.500 (.260–.740)	11/17 1.212
12	GDM	25/34 vs. 31/36; $p = .1548$	.735 (.564–.857)	.861 (.721–.944)	25/34 2.741
13	CDS	9/17 vs. 9/18; $p = .5651$	.529 (.278–.747)	.500 (.260–.740)	9/17 0.242
14	DBO	25/51 vs. 30/54; $p = .3176$	.490 (.347–.634)	.556 (.414–.691)	25/51−0.143
15	FBI	25/34 vs. 27/36; $p = .5522$	.735 (.564–.857)	.750 (.592–.866)	25/34 2.741
16	LPA	7/10 vs. 7/10; $p = .6858$	.700 (.381–.913)	.700 (.381–.913)	7/10 1.265
17	VPI	22/34 vs. 23/36; $p = .5709$	.647 (.465–.800)	.639 (.466–.790)	22/34 1.714
18	MPA	22/34 vs. 23/36; $p = .5709$	.647 (.465–.800)	.639 (.466–.790)	22/34 1.714
19	FMA	13/17 vs. 15/18; $p = .4656$	.765 (.511–.915)	.833 (.590−953)	13/17 2.185
20	RRO	8/17 vs. 14/18; $p = .0625$	.471 (.253–.722)	.778 (535–.920)	8/17−0.242
21	RBO	8/17 vs. 13/18; $p = .1202$	.471 (.253–.722)	.722 (.465–.883)	8/17−0.242
22	DFU	7/10 vs. 9/10; $p = .2910$	.700 (.381–.913)	.900 (.556–.995)	7/10 1.265
23	SCU	10/17 vs. 16/18; $p = .0487$	.588 (.337–.816)	.889 (.675–.980)	10/17 0.726
24	VPI	12/17 vs. 13/18; $p = .6043$	.706 (.456–.873)	.722 (.465–.883)	12/17 1.699
25	FCA	10/17 vs. 16/18; $p = .0487$	.588 (.337–.816)	.889 (.675–.980)	10/17 0.726
26	AMO	13/17 vs. 14/18; $p = .6203$	.765 (.511–.915)	.778 (.535–.920)	13/17 2.185
27	RMO	14/17 vs. 16/18; $p = .4715$	.823 (.583–.950)	.889 (.675–.980)	14/17 2.663
28	CZA	12/17 vs. 16/18; $p = .1768$	.706 (.456–.873)	.889 (.675–.980)	12/17 1.699
29	DFE	15/17 vs. 16/18; $p = .6766$	.882 (.663–.979)	.889 (.675–.980)	15/17 3.150
30	LAN	13/17 vs. 15/18; $p = .4656$	.765 (.511–.915)	.833 (.590–.953)	13/17 2.185
31	GSI	32/34 vs. 34/36; $p = .6710$	.941 (.811–.989)	.944 (.814–.990)	32/34 5.143
32	VTO	16/17 vs. 17/18; $p = .7429$	.941 (.722–.997)	.944 (.740–.997)	16/17 3.637
33	CAN	16/17 vs. 16/18; $p = .5221$	.941 (.722–.997)	.889 (.675–.980)	16/17 3.637
34	MCI	16/17 vs. 16/18; $p = .5221$	.941 (.722–.997)	.889 (.675–.980)	16/17 3.637
35	AFO	16/17 vs. 16/18; $p = .5221$	.941 (.722–.997)	.889 (.675–.980)	16/17 3.637
36	FVE	16/17 vs. 17/18; $p = .7429$	.941 (.722–.997)	.944 (.740–.997)	16/17 3.637
37	GMU	15/17 vs. 17/18; $p = .4779$	.882 (.663–.979)	.944 (.740–.997)	15/17 3.150
38	RPA	46/51 vs. 53/54; $p = .0900$	.902 (.792–.961)	.981 (.907–.999)	46/51 5.742

In the comparison between active and passive reversible sentences the p values resulting from each comparison were considered one-tailed. The underlined data are in line with the predictions based on the TDH.

sentences should fall along a Gaussian distribution, with a mean of 50% (for a binary choice task). None of the predictions was supported by the results of our study. Of the 38 patients tested, only 3 (7.9%) obtained significantly more accurate scores on active than on passive reversible sentences, and only 6 (15.8%) presented with both better-than-chance performance on actives and chance performance on passives. In addition, the distribution of the normalized proportions of correct responses to passive sentences (calculated for each subject) differed dramatically from the distribution we would have expected if agrammatic subjects had responded at chance to passive reversible sentences. These results confirm previous reports showing that agrammatic Broca's aphasics do not present with a homogeneous profile of sentence comprehension performance (Berndt et al., 1996; Caramazza et al., 2001) and they are clearly inconsistent with expectations derived from the TDH of Broca's aphasia.

What are the broader methodological and theoretical implications of the results reported here? Methodologically, the results confirm the view that aphasic

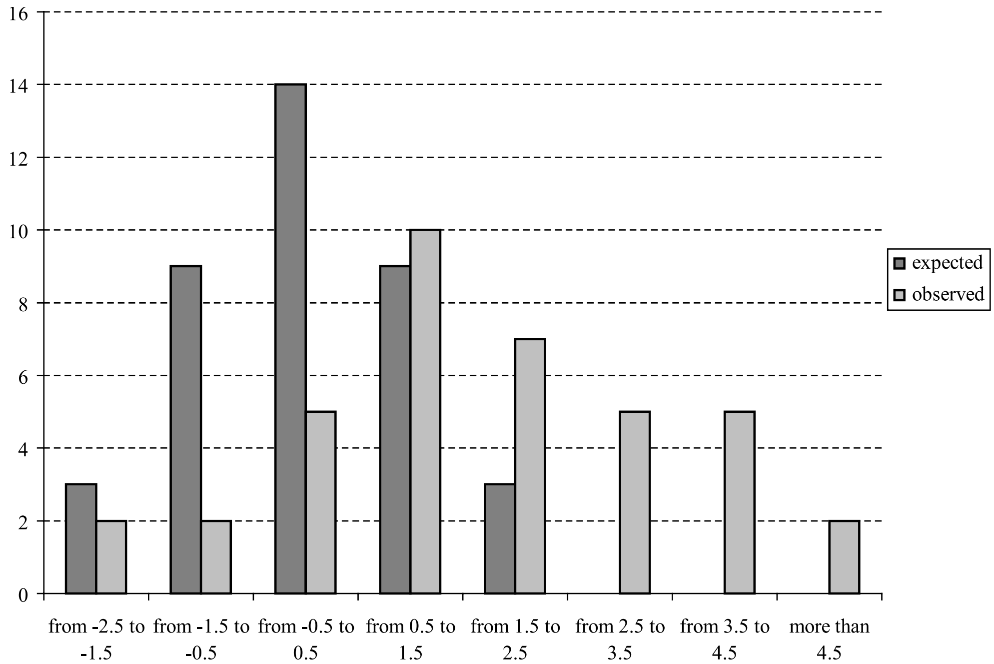

Fig. 1. Distribution of the normalized proportions of correct passives for each patient: the reported *z* points indicate the normalized distance of the observed proportion of correct passives from the rate of .500 expected assuming that agrammatic patients should be at chance with passive reversible sentences comprehension.

syndromes do not provide a valid basis for inferring the structure of cognitive processes or their neural substrates. In the case under consideration here, the subjects included in the study were all clinically classified as agrammatic Broca's aphasics and all had sustained lesions to Broca's area, and yet their comprehension profiles were clearly heterogeneous. Therefore, it makes little sense to ask what is the cause (singular) of the comprehension impairment in agrammatic Broca's aphasia. This is because there is not a single type of comprehension impairment associated with agrammatic Broca's aphasia. Instead, different types of comprehension performance are found in such patients, most likely reflecting different mixtures of damage to the various cognitive and linguistic mechanisms involved in sentence processing. This should not come as a surprise since brain damage is not constrained by the theoretical interests of the experimenter but by the vagaries of vascular and other forms of pathology in different subjects. These experiments of nature are extremely complex (typically involving large swathes of brain tissue and their associated functional roles) and highly irregular. Their commonalities may be far less important than their differences. Thus, the relevant units of analysis should not be arbitrarily selected subsets of such experiments (i.e., syndromes) but individual experiments of nature—individual patients—where through systematic and detailed investigations it is possible to tease apart the contribution of the spared and damaged mechanisms involved in the execution of a given a task (Caramazza, 1986; Shallice, 1979).

The results of this investigation also have implications for the ongoing debate on contrasting linguistic analyses of agrammatism. The (supposedly) random performance of agrammatic Broca's aphasics on passive reversible sentences in comprehension tasks has been the object of competing linguistic accounts (e.g., Beretta et al., 2001; Grodzinsky, 2000; Mauner, Fromkin, & Cornell, 1993). For example, there is an ongoing debate about whether the TDH or the Double Dependency Hypothesis[2] (Mauner et al., 1993) provides a better account for the comprehension impairment in Broca's aphasia. But, as we have seen, this debate is based on the false premise that there is a clear, uniform empirical fact to be explained, namely that agrammatic Broca's aphasics present with a comprehension profile characterized by chance performance on passives and normal performance on actives. The results reported here (but see also Berndt et al., 1996; Caramazza et al., 2001) clearly show that it is only a minority of Broca's aphasics that show the performance pattern that is fueling the linguistic debate; the majority of agrammatic aphasics do not show different levels of comprehension performance for

[2] This hypothesis is based on the assumption that a passive sentence contains two structural dependencies, the first comprised of the noun phrase corresponding to the subject and the foot of its chain, the passive trace; the second comprised of the noun phrase corresponding to the agent and the foot of its chain, the morphology of the passive sentence voice. When information on both dependencies is available, agent and theme role are correctly assigned in passive sentences. However, if the dependency between a noun phrase and the foot of its corresponding chain is disrupted, theta roles will be assigned at random.

actives and passives. In some cases performance is at chance for both actives and passives, in other cases performance is excellent for both, and in others still performance is poor but not at chance. Furthermore, the fact that agrammatic production and comprehension dissociate shows that attempts to provide a unified linguistic account for the syndrome are misguided since there isn't a unified phenomenon to be explained. We should note, however, that our rejection of the TDH and related hypotheses of agrammatic Broca's aphasia does not imply rejection of the possibility that some patterns of comprehension failure in aphasic patients, independently of their clinical classifications, reflect damage to components of the language processing system that are dedicated to syntactic analysis (as has been suggested by Dick et al., 2001).

The fact that agrammatic Broca's aphasia is not associated with a single pattern of sentence comprehension disorder does not mean that nothing in some of these subjects' comprehension deficits specifically relates to damage to some component of syntactic processing. The latter view has been recently proposed by Dick et al. (2001), who administered a sentence comprehension task to normal subjects under stressful conditions and to brain-damaged subjects presenting with different clinical forms of aphasia. These authors interpreted the facts that Broca's aphasics did not perform differently from other clinical groups, and that their performance profile was not dissimilar (only worse) to that observed in normal subjects under stress as an indication that there is nothing specifically syntactic about the comprehension disorder documented in agrammatic Broca's aphasia. Rather, they state that the disorder observed in these subjects lies in a continuum that includes normal performance at one extreme and severely disrupted aphasic performance at the other (see Ruml, Capasso, Miceli, & Caramazza, in press; for detailed discussion and critique of the "continuity thesis" as applied in the context of anomia). This position represents the extreme opposite from the one advocated by Grodzinsky (2000) and we think it is equally unjustified. The central weakness of this position is that it, too, considers only a narrow subset of patient's performance, ignoring the fact that such performance occurs in the context of other performance features that are not arbitrarily related to each other but are mutually constraining. Thus, for example, it matters whether a patient's performance in one task is highly predictive of performance in other tasks, allowing inferences about the shared mechanism implicated in those tasks. For example, the fact that a patient makes comprehension errors almost exclusively with reversible sentences (both active and passive) and makes reversal errors in production (e.g., describing a picture showing a boy kissing a girl as *The girl kisses the boy*) but has near perfect control of morphological processing in both comprehension and production would seem to imply a deficit in thematic role assignment that is independent of morphosyntactic processing (see Caramazza & Miceli, 1991; see also Martin & Blossom-Stach, 1986). This profile of performance contrasts instructively with that of a patient who performed normally in all comprehension tasks but was severely impaired in morphosyntactic processing (see Nespoulous et al., 1988; see also Bastiaanse, 1995; Caramazza & Hillis, 1989; Kolk et al., 1985; Miceli et al., 1983). These contrasting patterns of performance cannot be placed on a simple continuum but require assuming that morphosyntactic processes and thematic role assignment processes implicate, at least, some independent language processing mechanisms.

Finally, our results also have theoretical implications for theories of how language mechanisms are distributed in the neural substrate and how they can be affected by brain damage. Our subjects were selected on the basis of both clinical and anatomical criteria—they were all clinical cases of agrammatic Broca's aphasia, who had sustained damage to the left inferior prefrontal cortex, involving (but usually not restricted to) areas BA 44 and 45. One of the reasons for selecting these two criteria was Grodzinsky's assumption that Broca's area is essential for the co-indexation of traces and that damage to this area, with the resulting inability to process traces, is solely responsible for the sentence comprehension deficit observed in agrammatic Broca's aphasics. However, our results are clearly at odds with this expectation—we did not find a homogeneous pattern of comprehension failure in our consecutive series of agrammatic Broca's aphasics. Rather, as already noted, the results of the present study encourage a multi-component view of the language disorder(s) found in agrammatic Broca's aphasia (e.g., Caramazza & Berndt, 1985; Goodglass & Menn, 1985), which contends that the core deficits of the agrammatic syndrome result from damage to a set of independent mechanisms that tend to be damaged together because of the proximity in the brain. This proposal is in line with recent neuropsychological and neuroimaging evidence suggesting that the left inferior prefrontal cortex is involved, among other things, in working memory (e.g., Smith & Jonides, 1998), in morphosyntactic processing (e.g., Shapiro, Pascual-Leone, Mottaghy, Gangitano, & Caramazza, 2000), in phonological processing (e.g., Miceli et al., 2002), and in selecting a target form among competing representations (e.g., Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997). It is quite possible that different portions of the left inferior precentral gyrus are differentially involved in these functions. However, the fact that in a series of consecutive agrammatic speakers with damage to Broca's area only a small number of cases presents with the comprehension profile predicted by the TDH clearly militates against the proposal that the role of this portion of the brain is to provide the neuroanatomical substrate needed to process phonological traces (Grodzinsky, 2000).

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