

PROSODY AND BROCA'S APHASIA: AN ACOUSTIC ANALYSIS

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1. SUMMARY

In this study we present the first acoustic analysis on Italian prosody as produced by a set of Broca's aphasics. In particular, we focus on read and spontaneous speech of four right-handed non-fluent Tuscan aphasics, studied in comparison with a control group of normal speakers, with the same educational and regional background.

The analysis tries to check the maintenance of prosodic structures in the aphasic speakers and, in particular, their tone modulation in expressing the syntactic functions. Phonemic errors have been recorded and analysed too.

Our results agree with previous studies on the topic: speech timing is disrupted by the introduction of long pauses within the utterance as well as by the abnormal lengthening of all syllables. Intonation is damaged too because of frequent F0 resetting.

On the other hand, our aphasic subjects do not refer to prosodic structure in order to improve their linguistic competence, since mismatch between prosody and syntax is often found.

Keywords: speech pathology, aphasia, dysprosody.

2. INTRODUCTION

Expressive aphasia, a kind of non-fluent aphasia also known as Broca's aphasia, is a linguistic deficit caused by damage to anterior regions of the brain, including the left inferior frontal region known as Broca's area, corresponding to Brodmann's areas 44 and 45 (see Brookshire, 2003; Caplan, 1987; Davis, 2000; Shirmer *et al.*, 2001, Nicolai, 2003).

People suffering from this form of aphasia frequently exhibit agrammatism. Language performance is highly compromised and speech production is reduced to disjointed words so that morpho-syntax is very poor, with omission of function words and inflection. Clinical evidence has shown a better preservation of competence in comprehension and reading (both decodification tasks) with respect to speech or writing (codification). During reading tasks, repair strategies are usually adopted so that the patients make attempts to correct their errors.

Troubles experienced by Broca's aphasics in controlling their phonological structure in both segmental and suprasegmental levels reveal a deficit due to lesions in the left hemisphere. In particular, these patients are not able to regulate timing and F0 patterns over a rather extended prosodic domain, because their speech programming is constrained to small units of speech (see Danly *et al.*, 1979; Danly & Shapiro, 1982; Gandour *et al.*, 1989).

More relevant is the issue related to hemisphere specialization: left-hemisphere dominance is currently assumed for 'core' (i.e.

representational) linguistic functions in right-handed adults (Caplan, 1987). In this domain, an fMRI study (Shirmer *et al.*, 2001) has recently demonstrated how prosody may be processed by both the hemispheres. The prosodic aspects (in particular, speech timing) strictly related to the linguistic structure are performed by the left hemisphere, whereas the emotive and affective prosody is related to the right hemisphere. As a result, Broca's area seems to be involved in prosody inasmuch it conveys linguistic information, although there may be other areas in the brain with overlapping functions.

Broca's aphasic patients show some recurrent phonological features:

- non-fluency, i.e. slow and laboured speech (Danly *et al.*, 1979; Danly & Shapiro, 1982);
- agrammatism or telegraphic speech (Davis 2000);
- paraphasias, i.e. target words replaced by phonetically similar words (Brookshire, 2003).

In particular, speech output by Broca's aphasics has been often described as dysprosodic. Although the clinical use of this linguistic term is ambiguous, as referring to all aspects of prosody, it seems to have been adopted with primary reference to a remarkable deficit in F0 programming. The most relevant features recoverable in literature are:

- impairment of melodic modulation;
- isochrony of syllables;
- alteration of speech timing.

Only a few studies specifically deal with the subject of dysprosody in Broca's aphasics. cursory reference is present in international literature (Brookshire, 2003; Danly *et al.*, 1979; Danly & Shapiro, 1982; Gandour *at al.*, 1989; Kean, 1987; Sarno, 1988). However, up to now no dedicated study on patients speaking Italian has been reported neither in clinical nor in linguistic circles.

3. ANALYSIS

The main goal of our study is to verify whether the prosodic derangement in Broca's aphasia could be interpreted with reference to pathological factors due to a primary impairment in speech timing, as already suggested (Danly *et al.*, 1979; Danly & Shapiro, 1982).

Our study regards 4 non-fluent aphasic subjects. The speakers, 3 males and 1 female, aged between 53 and 72, all come from Tuscany (two from the area of Pisa, two from the area of Florence). The Broca's aphasia have been diagnosed on the basis of the test Milano II, performed at the Clinical Hospital of Pisa.

All patients have had an ischemic stroke that caused a single focal lesion in the left hemisphere. They met the cerebral accident by one year at least at the moment of the recording and show a general expressive deficit; understanding is well-preserved and word repetition is only partially compromised.

In order to compare the data relative to aphasics with data referring to normal speech, we also analyzed a control group of two healthy

Tuscan speakers, having the same educational and regional background as the patients.

The audio material of aphasics has been recorded during rehabilitative sessions of speech therapy at the Hospital, whereas normal speakers have been recorded in the Laboratory of Phonetics at the Department of Linguistics, University of Pisa.

For both classes of speakers (aphasic and healthy subjects), our protocol includes:

- a. samples of spontaneous speech;
- b. speech elicited on fixed topics;
- c. reading of a passage purposely defined for prosodical analysis.

In particular reading allows us to examine a series of utterances produced with different syntactic and pragmatic modalities.

The analysis has developed through different phases:

1. auditory analysis;
2. spectro-acoustical analysis;
3. comparison between qualitative and quantitative data of the aphasics and the control group.

The recorded material has been sampled at 22.050 Hz with software *Multispeech 3700* (version2.5) by Kay Elemetrics. The acoustic analysis has been performed with software *PRAAT*, version 4.6.31.

We adopted the following parameters:

- total duration of the breath-group in milliseconds (ms);
- speech rate (σ /sec.);
- pitch range and pitch values (Hz) at the beginning (onset) and at the end (offset) of the breath-group;
- melodic shape of the final syllable, classified according to the following categories: rising, falling, rising-falling, falling-rising, flat.

The data collected have been inserted into a database developed in our Laboratory of Phonetics. The sociolinguistic indexes inserted in DB refer to regional area, age, education and gender of the speakers, whereas the acoustic parameters concern F0 and duration.

The structure of our DB requires the insertion of every utterance under examination, i.e. each breath-group previously selected within the recorded audio file. The specific reference to every patient – identified by an anonymous acronym – is therefore inserted with diatopic indexes, specifying the regional origin. Finally, the different basic pitch contours are inserted too, according to the specific pragmatic value they have (declaration, question, etc.). The structure of the Db allows us to question different parameters in a parallel way and to find out crossed reports with reference to the prosodic patterns of each speaker.

4. RESULTS

4.1 Rhythmic patterns

Our research highlightens a strong alteration both of rhythmic competence and syntactic parsing of Broca’s aphasics. The melodic and rhythmic structures turn out to be remarkably compromised and dysprosodic in comparison with the healthy subjects analyzed.

A substantial aspect is the sensitive lengthening of the utterance duration, which is nearly double for the aphasics in comparison with the controls. Interphrasal pauses are frequent and very long. Moreover, we noticed that pauses often do not correspond to relevant syntactic boundaries. Therefore, speech rate tends to decrease in direct proportion to the number of syllables of the utterance (see Table 1). This slowing is due to the general lengthening of the utterance and to the frequent pauses that make the prosody aberrant.

<i>Subjects</i>	Aphasics				Non aphasics	
	GG-F	PA-M	EF-M	BS-M	DD-M	MF-M
Art. rate (σ /sec)	0.32	0.33	0.27	0.53	0.6	0.7

Table 1: Articulation rate (σ /sec) of aphasic and non aphasic speakers.

Being supra-laryngeal voice settings abnormal, sound targets are frequently deranged, especially in case of concomitant oro-facial apraxia.

At the prosodic level, the more evident feature is an unnatural hyper-segmentation of the verbal sequence, especially in reading the text, so that a production word-by-word is frequent. The high number of declination resets made the evaluation of the pitch range difficult. This finding could be due to a specific trouble in programming wide focus structures: as already shown by Schirmer *et al.* (2001), the size of the domain over which the prosodic pattern has to be planned is crucial.

As regards melodic patterns, acoustical analysis revealed a significant compression of the pitch contour, compared with that of the control group. In particular, for male speakers the pitch range is lower than 150 Hz, while for the female speaker, the pitch shows F0 values comparable to those of normal male speakers (with a maximum pitch value still lower than 300 Hz).

Because of the general low rate of speaking, no final lengthening has been found in our aphasic patients, in agreement with previous analysis on Broca's subjects (see Danly *et al.*, 1979; Kean, 1987), in disagreement with the control speakers.

4.2 Modalities and pitch contours

As we already pointed out, we have considered different modalities, namely declaration and question. The intonational analysis focuses on pitch range, syllable duration and shape of the final melodic interval of the utterance starting from the last stressed syllable

up to the last unstressed one. The same parameters have been measured both for the aphasics and for the controls.

4.2.1 Declaration

In declarative sentences – both in spontaneous and in read speech – a general flattening of the pitch contour is found in the aphasic subjects. Because of the reduction of melodic range, a monotonous speech effect is usually perceived simply by ear. Sometimes a weak and constant trend towards a falling tone – which is typical of the declarative modality – copies the declination line performed by normal speakers. In table 2 we present the pitch values detected in declarative modality; see also Figure 1.

<i>Subjects</i>	EF-M	BS-M	GG-F	PA-M
	DECLARATIVES			
Initial F0	-	199	211	117
Maximum F0	-	220	263	141
Minimum F0	-	134	153	95
Final F0	-	134	187	102
Pitch Range	-	86	110	46
Duration	3178	1790	2948	2868

Table 2: Values of pitch (Hz) and duration (msec.) in the declarative sentences of aphasics.

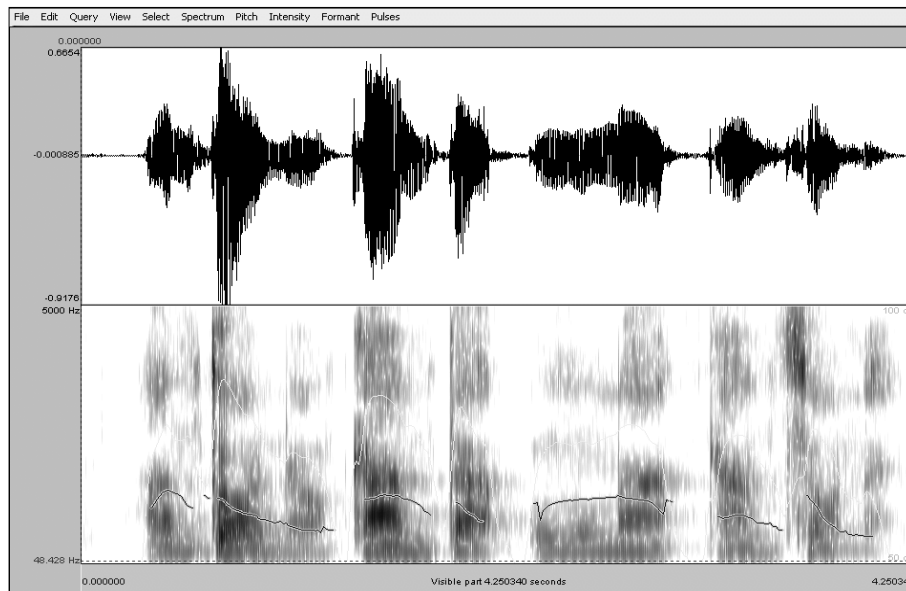


Fig. 1: Soundwave, spectrogram and F0 contour of the utterance
Antonio canta una canzone “Antonio is singing a song”
as produced by an aphasic patient

In general, melodic patterns of the aphasics are comparable with those of normal speakers, the main difference consisting of a different prosodic parsing of the sentence (see before, § 4.1). However, a final rising is sometimes found at the end of the utterance, especially in read speech. This continuation contour could be due to a general trouble in programming the linguistic performance, as reported in literature (cf. Sarno 1988).

4.2.2 Yes/no questions

In the aphasic patients, the final melodic contour of *yes/no* questions seems to be often marked by F0 rising movements up to the stressed syllable (see Figure 2).

As shown in Table 3, the F0 offset is high (but less than in *wh*-questions). The pitch range of the breath-groups is reduced, whereas the tonal rising of the final segment is relatively high.

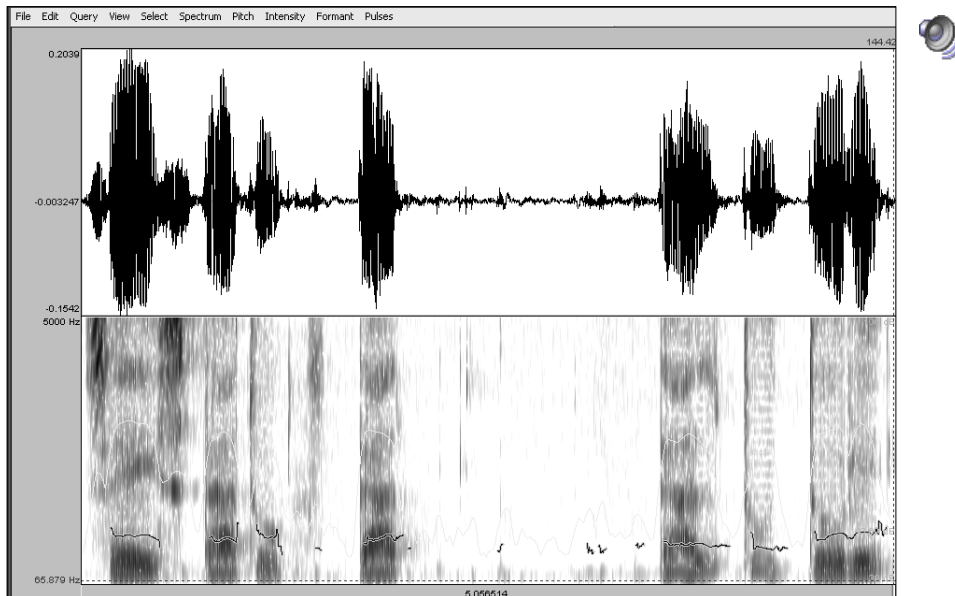


Fig. 2: Soundwave, spectrogram and F0 contour of the utterance
Sei stato dal dottore? "Have you been at the doctor's studio?"
as produced by an aphasic patient.

In the control subjects, the more representative final melodic contour is rising-falling, according to previous results for this area of Italy (see Marotta & Sorianello 1999; 2001); a sensitive modulation on the final stressed syllable is appreciated too.

<i>Subjects</i>	EF-M	BS-M	GG-F	PA-M
	YES/NO QUESTIONS			
Initial F0	99	152	215	115
Final F0	81	72	204	109
Pitch Range	31	151	100	39
Duration	1516	3172	2305	1327

Table 3: Values of pitch and duration in *yes/no* questions.

4.3.3 Wh- questions

For our aphasic subjects the most frequent tonal pattern on *wh*-words is rising-falling; sometimes, a high-flat contour occurs too (especially when the interrogative morpheme is bisyllabic). At the end of the utterance, the final stressed and post-tonic syllables show a rising movement, especially in read speech. F0 values are all quite high, so the overall pitch range is more consistent than elsewhere (see table 4). The melodic profiles seem therefore to be comparable with the typical high-flat contours of the controls (see Marotta 2001; 2002).

<i>Subjects</i>	EF-M	BS-M	GG-F	PA-M
	<i>WH- QUESTIONS</i>			
Initial F0	103	152	258	131
Final F0	80	72	207	1178
Pitch Range	37	151	123	43
Duration	3285	1946	2039	1681

Table 4: Values of pitch and duration in *wh-* questions.

An example of pitch contour for a *wh-question* as produced by an aphasic patient is given in Figure 3.

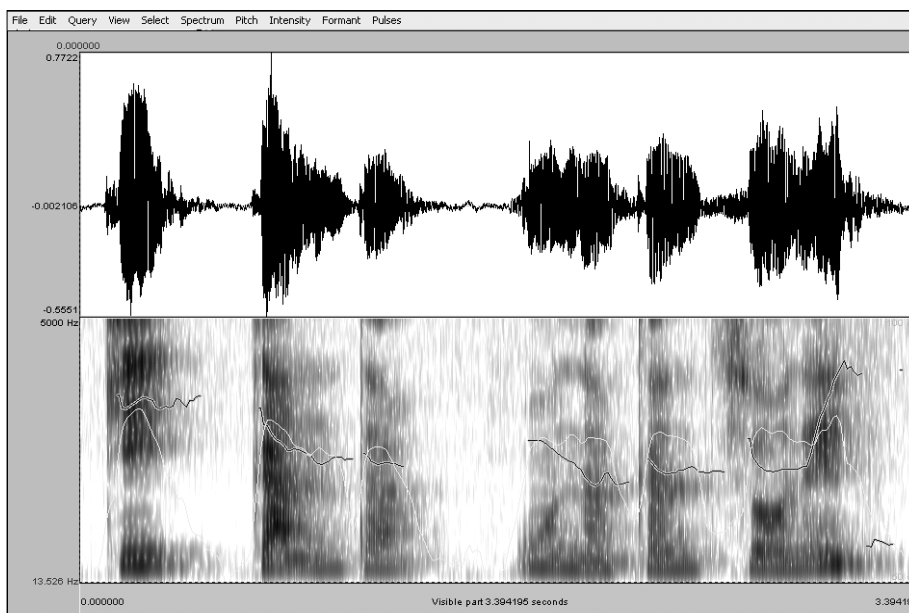


Fig. 3: Soundwave, spectrogram and F0 contour of the utterance *Chi canta una canzone?* “Who is singing a song?” as produced by an aphasic patient.

5. SYLLABLE STRUCTURE

The phonological troubles experienced by the aphasics during the speech tasks regard both segmental and suprasegmental aspects. Traditional literature on clinical linguistics usually distinguishes between paradigmatic and syntagmatic errors: the first kind consists in substitutions of segments or features; the second one includes metathesis and syllable iterations (see Joannette *et al.* 1980, Guyard *et al.* 1981).

These kinds of errors often show an interesting correlation with the syllable structure of the target words. For instance, we have recorded cases of consonant deletion in coda position (e.g. [la_ 'kwa:dra] = *la squadra* “the team”) or reduction of complex onsets, as in the following examples:



[ten'di:no] = *Trentino*;



[mi:'nesta] = *minestra* “soup”.

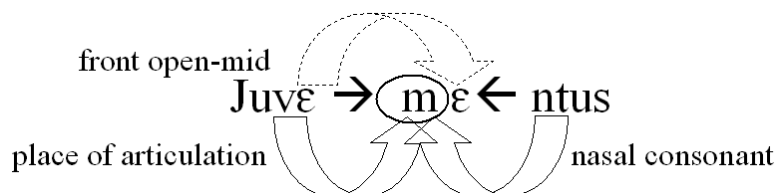
The omission of consonantal phonemes at the beginning of the word is also represented, in our corpus; for instance in by the lexical output [_ 'uŋgi] instead of *lunghi* “long”.

Some segments show consonantal assimilation by manner (e.g. [sfor'ti:vo] = *sportivo* “sporting”) and even by place of articulation (e.g. [su's:ɛs:o] = *successo* “success”). All these phenomena show a clear trend towards the minimal effort in the articulation of speech sounds.



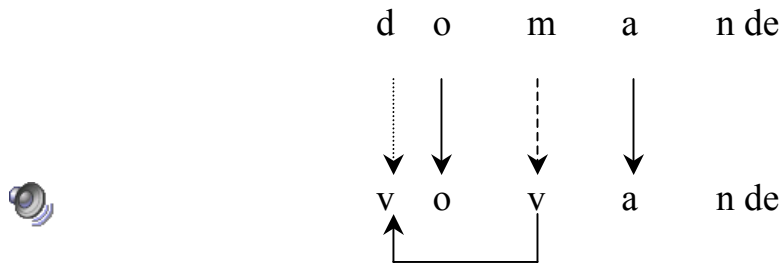
Metathesis consists in the exchange of position of phonemes, clusters of phonemes or single syllables within the word, for instance in the case of [tʃenta'kat:o] = *centrattacco* “centre forward”

The production of a new syllable is also possible; in this case the segments added have some phonological features in common with the adjacent ones. As shown in the scheme below, in the case of the target word *Juventus* [ju'ventus], the name of an Italian football team, the output produced by the aphasic patient is [juvɛ'mentus]: the close-mid vowel [ɛ] has spread to a new syllable, where the consonant in onset has taken the place of articulation and the nasality from the preceding and following syllable, respectively. We show the occurring processes in the following schema:



Another phonological process rather common in our corpus is consonant assimilation; for instance, the place assimilation is reduplicated in successive syllables in the case of *domande* “questions”, produced as [vo'vande]: the distorted output shows the labial place of articulation of the second target consonant which spreads to the preceding one; the bilabial nasal [m] becomes

labiodental fricative [v], where the fricative manner of articulation indicates a consonantal weakening:



We also found the so-called *conduites d’approche*, i.e. phonemic repetitions made by the speakers to approximate the lexical target. In agreement with previous studies (see e.g. [7]), our aphasic speakers frequently iterate the initial syllable, for instance in [pa.pa.pa.ba.'baŋko] = *banco* “bench”; [fo.ko.go.go't:ʃa] = *gonfia(re)* “to swell”. In some cases the repetition involves specific syntagmatic elements, such as the article or the first syllable of a noun; for instance,

[ka'skaθo le 'vɔ. le 'vɔ. le 'fɔ.ʎ:ɛ 'fɔ.ʎ:ɛ]
cascate le foglie “fallen the leaves”

6. CONCLUSIONS

Our experimental data agree with the outcomes of previous studies on Broca's aphasics.

The main result concerns the rhythmic structure of the disordered speech as produced by aphasic patients. We could say that in our subjects prosodic patterns are broken because of long-lasting and recursive pauses and anomalous lengthening of all syllables. This also provides a sensitive measure for a remarkable deficit in planning a speech output longer than the word duration.

Melodic structure is compromised too. In agreement with the rhythmic segmentation of the utterances, F0 resetting is frequent, some lowering of the pitch range appears to be anomalous. Furthermore, in strong contrast with the control group, the parsing is not aligned with the syntactic structure of the utterance, sketching out the altered pattern typical of Broca's aphasics.

A crucial point concerns the relation between speech timing and melody: which of the two levels is the primary source of dysprosody? We know that the brain damage in Broca's area involves a general motor retardation in speech articulation. Then, a direct effect should be a narrower-than-normal scope for linguistic planning, with a remarkable lengthening in segmental duration (see already Danly & Shapiro 1982).

The hypersegmentation of the target utterance is due to an increase in the number and duration of pauses; as a consequence, intonational phrases do not correspond to syntactic or pragmatic groups any more,

but are constrained by speech timing, so that the disruption of rhythmic structures seems to be responsible for the disruption of the melodic structures.

We conclude that this relation could be interpreted as a drift effect that causes a projection of the timing patterns onto intonational patterns, producing a complex dysprosodic synergy in which non-modal voice qualities (both laryngeal and supra-laryngeal) are probably relevant features too.

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