# Effects of syllabic complexity in predicting accuracy of repetition and direction of errors in patients with articulatory and phonological difficulties

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## Abstract

The purpose of this paper is to demonstrate the existence of a strong and significant effect of complexity in aphasia independent from other variables including length. Complexity was found to be a strong and significant predictor of accurate repetition in a group of thirteen Italian aphasic patients when it was entered in a regression equation either simultaneously or after a large number of other variables. Significant effects are found both when complexity was measured in terms of number of complex onsets (as in a recent paper by Nickels and Howard, 2004) and when it was measured in a more comprehensive way. Significant complexity effects were also found with matched lists contrasting simple and complex words and in analyses of errors. Effects of complexity, however, were restricted to patients with articulatory difficulties. Reasons for this association and for the lack of significant results in Nickels and Howard (2004) are discussed.

Much research has been devoted to investigating the variables affecting retrieval of word forms from a semantic specification (lexical access). Studies with both normal and aphasic speakers have shown that word frequency, age of acquisition, concreteness and grammatical class are all crucial variables in accessing word forms (e.g., Levelt, Roelofs & Meyer, 1999; Lewis, Gerhand & Ellis, 2001; Berndt, Haedinges, Burton & Mitchum, 2002). In contrast, length effects have been considered the hallmark of stages following lexical access. The presence of length effects have been associated with ‘phonological encoding’, the stage where the phonemes corresponding to a given word are retrieved and ordered (e.g., Buckingham, 1992; Kohn, 1989; Nickels, 2001; Levelt et al., 1999) and with problems in maintaining phonological activation over time while articulation is taking place (Shallice, Rumiati & Zadini, 2000).

In contrast, comparatively little research has been devoted to the factors affecting the computation of an articulatory program from a phonological specification. A variable that one would expect to act at this level is syllabic complexity. Clinicians have long suggested that trouble articulating complex syllables is a defining characteristics of patients suffering from apraxia of speech, a deficit thought to involve articulatory planning rather than phoneme retrieval (e.g., Duffy, 1995, McNeil, Robin & Schmidt, 1997; Rosenbek, 2001). However, effects of syllabic complexity have lacked a firm empirical/experimental footing with the result that they have largely been ignored both in models of normal word production and in clinical practice. For example, standardised batteries for the assessment of aphasia neither test nor control for effects of syllabic complexity.

A recent paper by Nickels and Howard (2004) has argued that syllabic complexity makes no significant contribution to predicting correct/incorrect repetition in any of a series of aphasic patients. Although the paper should be applauded for focusing on a difficult and under-researched issue, it may strengthen the feeling that effects of syllabic complexity in aphasia are non-existent and/or irrelevant. This would be unfortunate since we believe there is accumulating evidence for effects of syllabic complexity in aphasia as well as in other domains. In the present study, we will examine closely the results of Nickels and Howard (N & H from now on) to understand their lack of positive results. In addition, we will show that strong and significant complexity effects are indeed present both in the correct performance of aphasic patients and in their errors. First, however, we will review evidence of complexity effects from the literature.

Cross-linguistic evidence of syllabic complexity. The distribution of syllable types between and within languages supports the claim that certain structures are more complex than others. It is well known that certain syllable types (one would argue the simple types) are present in most languages and, within languages, they are used very often. Other types are used infrequently both between and within languages. Moreover, if a language has syllables at a certain level of complexity, it will also have all the types of lower complexity (e.g., Greenberg, 1978). Using distributional evidence, linguists have constructed hierarchies of complexity which rank syllables according to the sequence of consonants and vowels (consonant-vowel templates). All languages have syllables with a single consonant plus a vowel (CV syllables) and complications are progressively rarer. If each variation of the consonant-vowel template is considered an added complexity, one can construct a hierarchy like the following (from Kaye & Lowenstamm, 1981; Clements & Kaiser, 1983):

| | |
|---|---|
| Simplest | 1. CV |
| | 2. CCV; V; CVC |
| | 3. CCCV; CCVC; VC |
| Most complex | etc.. |

In addition, the frequency of syllable types varies within the same consonant-vowel template, depending on which segments make up the syllable. For example, syllables like /tra/ are more common than syllables like /nra/. One way to explain this variation is in terms of sonority. In perception, sonority corresponds to the relative loudness of segments, in production to the openness of the vocal tract. In spite of the difficulty of defining sonority in formal terms, there is good agreement on the relative sonority of different speech sounds as shown below (e.g., Steriade, 1982):

| | Stops > | Fricatives > | Nasals > | Liquids > | Glides > | Vowels. |
|---|---|---|---|---|---|---|
| e.g.: | [t,d] | [s,f] | [n,m] | [l,r] | [y,w] | [a,i] |

According to Clement's Sonority Dispersion Principle (Clements, 1990), the simplest (more commonly used) syllables are those where there is a maximal, sharp rise in sonority from the edge of the syllable to the peak (the vowel) and little or no decrement afterwards (e.g., /ta/). These syllables produce a cycle with sharp periodic alternations in sonority. Syllables with a flatter profile are less preferred (e.g., /prya/). Syllables can be ranked according to how well they correspond to the optimal sonority profile and this ranking well accounts for differences in frequency of occurrence of syllables even within the same template (e.g., in onset, /ta/ is better than /ra/; in coda, /ar/ is better than /at/).

In linguistic theory, structures with a wider distribution within and between languages are generally referred to as less marked. Markedness statements, however, do not answer the question of why the 'better' (less marked/less complex) syllables have a wider distribution. In order for hierarchies of markedness to be more than self-fulfilling statements, one needs to find out what it is that makes a structure more or less widely distributed. The evidence presented next supports the claim that markedness is more than an abstract principle, but it has its roots in the physical ways in which humans perceive and produce language. According to this view, markedness principles should be reflected in the speech of both young children and patients with articulatory difficulties. The easier syllables should appear first in the repertoire of young children and they should be those that are more preserved in the speech of aphasic patients. In addition, both the errors made by children and those made by aphasics should reduce more complex/marked structures to simpler structures. In the rest of the paper, following others (e.g., Clements, 1990; Ouden, 2002), we will use the terms markedness and complexity interchangeably. The reader, however, should understand that our aim will be to provide evidence that markedness constraints have their basis in articulatory complexity.

Developmental evidence of syllabic complexity. There is evidence of syllabic simplifications in the speech of young children. Many studies have reported a tendency to reduce consonant clusters to a singleton, thus reducing a CCV template to a simpler CV template (Bernhard & Stemberger, 1998; Ingram, 1974; Smith, 1973; Spencer, 1988). In addition, an elegant study by Ohala (1999) has shown that the simplifications are in accordance with the sonority dispersion principle. Of two consonants, the child will produce the one which optimises the sonority profile of the syllable. Thus, he/she will preserve the least sonorous consonant in onset and the most sonorous consonant in coda. These results both strengthen the link between syllabic complexity and sonority and argue that complexity is a language universal.

Evidence of syllabic complexity in aphasia. Effects of complexity are also evident in the speech errors made by aphasic patients. As is the case for children, a number of studies have reported that aphasic patients delete consonants in complex onsets or codas much more often than in simple onsets (Beland, Caplan & Nespolous, 1990; Blumstein, 1978; Mackenzie, 1982). In addition, it has been reported that aphasic patients systematically eliminate hiatuses --sequences of two full vowels-- by either consonant epenthesis or vowel deletion (Buckingham, 1990; Beland & Favreau, 1991; Beland & Paradis, 1997). Hiatuses have a reduced distribution in the languages of the world (Dell & Elmedlaui, 1986; Guerssel, 1986) and, according to the sonority dispersion principle, they are complex because they provide no contrast in sonority between adjacent syllables.

Romani & Calabrese (1998) have analyzed all the different types of errors made by a Broca's aphasic, DB, to see whether his simplifications were systematic. They found a strong tendency to simplify across the whole error corpus. Deletions increased progressively in frequency with the complexity of the syllable type (in terms of CV template and in terms of sonority). In addition, as shown by children, deletions generally affected the most sonorous of the consonants of a complex onset, optimizing the sonority profile of the resulting syllable. As predicted by the Sonority Dispersion Principle, substitutions decreased sonority in onset, but not in coda (although coda substitutions were few). Insertions were often used to eliminate hiatuses by consonant epenthesis. Finally, transpositions generally involved high sonority segments (liquids and glides) embedded in complex structures. Thus, they also revealed difficulty in processing these structures.

In a subsequent study, Romani, Olson, Semenza and Grana' (2002) found no simplification tendency in a fluent patient, MM, although the severity of her impairment and the general characteristics of her errors were similar to DB's. This shows that a strong effect of complexity may occur in some patients, but not in others. In addition, this study suggests that there is an association between syllabic complexity and articulatory difficulties since these were present in DB but not in MM.

Evidence of complexity across domains. Beland and Paradis (1997) and later Paradis and Beland (2002) have compared the adaptations which French words undergo when borrowed by other languages with the syllabic errors (defined as segment deletions and insertions as opposed to segment substitutions) made by patients with primary progressive aphasia. They found strong similarities. Both in the case of loan words and in the case of phonemic paraphasias, most of the syllabic transformations occurred on marked syllables defined as modifications of the universally-unmarked CV syllable. Like we will do in our experimental investigation, Beland and Paradis have considered six contexts as marked: complex onsets, codas, complex codas, hiatuses, diphtongs, and word initial empty onsets (these are single vowel syllables in word initial position). These contexts are marked precisely because they are prohibited by some languages. Beland and Paradis have found that the syllabic errors made both aphasic patients and by normal speakers borrowing words which violate constraints of their language reduce these marked contexts to more simple CV syllables. Paradis and Beland (2002) have added a third leg to the argument by showing that (six years old) children, whether normal or with a 'phonological awareness disability', also simplify marked structures through insertions and deletions [1].

Effects of complexity in correct performance. In contrast to the error analyses reviewed above, N & H reported no effects of complexity in predicting the accuracy of repetition in a group of nine English-speaking aphasic patients. They used regression analyses to see which variables would predict correct performance. Pitting complexity against length and syllable length, they found that while number of phonemes was often a good predictor of correct performance, complexity was never a significant predictor after length was taken into account. These findings are puzzling. Why should patients show evidence of complexity when performance is analysed in terms of errors and not when it is analysed in terms of number correct? We will address this inconsistency. First of all, we will review the results of N & H and discuss some methodological problems. Secondly, we will present results from our own group of patients showing that using materials which do not disadvantage complexity, strong effects of complexity are found even when performance is analysed in terms of item correct and incorrect. Finally, we will show that analyses in terms of number correct and analyses in terms of errors represent two sides of the same coin Those patients who show complexity effects in analyses of correct performance are the same ones who show complexity effects when their performance is analysed in terms of errors.

## THE STUDY BY NICKELS AND HOWARD (2004)

N & H reported six analyses of syllabic complexity in relation with other variables (a seventh analysis was about syllable frequency, a related but independent point).

The first three analyses involved two sets of words: one contrasting lengths of three, four, and five phonemes, and the other contrasting lengths of four, five, and six phonemes (List 1). Analysis 1 examined effects of phoneme length controlling for number of syllables. Most patients

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[1] Beland and Paradis (1997) and Paradis and Beland (2002) have also shown that the aphasic errors and the children's errors differed from the adaptations of loan words in that they involved more segment deletions, while the adaptations involved more segment insertions. They attributed this difference to the fact that normal speakers obey a principle which calls for preservation of existing phonological material in the derived word. This leads to insertions rather than deletions. In the aphasics and in the children, however, the preservation principle may be in conflict with constraints which limit the complexity of the transformation of the original word and/or the metrical complexity of the resulting word. This leads to more deletions.

showed a significant effect of length. However, since longer words are systematically more complex, Analysis 1 provides equal evidence for length and complexity. Analysis 2 showed a significant effect of number of syllables controlling for number of phonemes in three patients, but results were reversed: words with more syllables were repeated better rather than worse. These results, instead, are consistent with effects of complexity since words that have more syllables must be simpler if they have the same number of phonemes. Analysis 3 used regression to assess the significance of syllable length once phoneme length and complexity (measured as number of consonant clusters) were controlled. This analysis showed no effects of syllable length. This strengthens the claim that the effects of syllable length shown by Analyses 2 (which controlled for phoneme length) were indeed due to syllabic complexity (the significance of complexity is not reported).

Analyses 4 and 5 were based on a second list which involved monosyllabic words contrasted along three dimensions: 1) the presence or absence of a complex onset; 2) the presence or absence of a coda; 3) the presence of a simple or complex coda. Analysis 4 examined relative performance with these types of words. Three patients showed significantly worse performance with the more complex words and another two showed a trend in the same direction. However, since more complex words were longer, this analysis, like Analysis 1, provides equal evidence for length and complexity. Analyses 5 and 6 were crucial since they directly attempted to disentangle effects of complexity and length. Analysis 5 (on List 2) showed no independent effect of complexity after phoneme length was taken into account. Analysis 6 (on List 1) showed that there were four patients with effects of length independent of complexity, but no patient with the opposite pattern (effects of complexity independent of length).

Indeed, it could be that N & H’s group of patients does not show independent effects of complexity (see later for a discussion of differences between patient populations). Before drawing this conclusion, however, is important to consider two factors which may have lead to insignificant results: whether the materials used by Howard and Nickels did indeed allow effects of complexity to be distinguished from effects of length and whether complexity was properly measured.

Table 1 shows the distribution of words of different lengths and degrees of complexity in the corpus of words used by N & H. Since only patients who showed a length effect in picture naming were included in their study, it is a given that length will be significant in the regression analyses.

However, inspection of the stimulus lists shows that complexity varies little in words of the same length. In List 1, there is some variability in complexity between words of the same length. However, the N in the cells that contrast complexity and length is small. In List 2, there is practically no variability in complexity between words of the same length. This means that complexity has no chance to emerge as an independent factor: all the variability in complexity is accounted for in terms of phoneme length.

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Insert Table 1 about here

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There is another factor which limits the usefulness of N & H regression analyses. Not only is complexity confounded with length (while the reverse does not hold), but it has been measured in a questionable way. N & H have considered only the number of intra-syllabic clusters (complex onsets and complex codas) and ignored other types of complex structures. Thus, hetero-syllabic clusters involving a simple coda and the following onset (e.g., ‘sul.tan’; ‘fan.cy’) have been considered to be as simple as CV sequences. This contradicts the widely held belief that syllables made by single consonant and a vowel (CV) are the best/simplest syllables, and other structures including syllables with a coda (CVC) represent complications. English words often end with a coda (e.g., token; spirit, sleep, snail). Thus, one may argue that word final codas should not be considered more complex. However, there is no justification for considering word medial syllables with a coda on par with CV syllables. Equally, other structures should be assigned a degree of complexity. Syllables consisting of a single vowel (V) should be considered more complex than CV syllables. Single vowel syllables occur both in word-initial position (e.g., ‘e.vil’, ‘a.lert’, ‘a.byss’) and, in the body of the word as hiatuses (e.g., ‘po.et’). As we have mentioned, hiatuses provide clear evidence of their complexity. Finally, English words commonly include dipthongs (e.g., ‘fuel’, ‘tiger’, ‘saint’, ‘house’). It is not completely clear how dipthongs should be categorized in terms of syllable structure, but words including them are likely to be more complex that similar words including only simple vowels. Since a large number of words which were classified as having no complex clusters had, in fact, other complex structures (especially within List 1) this may have diluted effects of complexity.

Clearly, there is the need to analyse complexity using a more fine-grained metric where different kinds of complexities are counted and can sum to provide an overall measure of the complexity of a word. Such a metric would also ameliorate the problem of confounding between complexity and length. Everything else being equal, a word with a complex onset will be longer than a word with a simple onset. However, if a more sophisticated metric is used, not all structures have this problem. In the case of word initial vowels or hiatuses the relation is inverted: the words with the complex structure are, in fact, shorter than the corresponding words with the same number of syllables but without the structure (e.g., V.CVC [e.vil] shorter than CV.CVC [me.rit]; CV.VC [ca.os] shorter than CV.CVC [ca.rot]). Thus, errors on words with these complex structures cannot be attributed to length. Our experimental investigation will analyse complexity using such a metric in a corpus of words where length and complexity are better distributed and in a subset of words contrasted for complexity but matched for phoneme length and other variables.

## EXPERIMENTAL INVESTIGATION

### Patient Selection and Classification

Clinical information

Patients were selected from the pool of aphasic patients being treated for rehabilitation at Fondazione Santa Lucia in Rome according to the following criteria: 1) stable condition; 2) willingness to participate in the study; 3) the presence of phonological errors in speech production; 4) a good phonological input. In addition, N & H’s patients had to show a length effect in picture naming. We did not use this last criterion since it biases results in favour of finding length rather than complexity effects.

With one exception, all our patients suffered from a left CVA. Patient GM had suffered from a right parietal CVA. Eight were males and three females, they were between 30 and 71 years old (average =47.8; SD=13.3), they were between 2 and 17 months post onset (average 11.0; SD=8.7) and had between 8 and 17 years of education (average = 12.3; SD=3.3). Individual clinical details are reported in Appendix 1. All patients were tested individually in the rehabilitation unit of the clinic. Sessions lasted approximately one hour each. Each patient was tested over a period of between 2 and 24 months. All patients remained stable during this time.

Seven patients were originally clinically classified as dysfluent by a trained speech therapist and six as fluent (dysfluent: DC, EM, AV, DG, MI, GC, AP; fluent patients: MC, TC, MP, AC, RM, GM). A diagnosis of dysfluency was based on two criteria: 1) slow and effortful speech with hesitations both between and within words; and/or 2) the presence of phonetic errors (as well as phonological errors) and groping for a response.

## Speech analyses

To assess speech quality, we carried out a set of more detailed analyses. Since we were interested in articulatory/phonological difficulties and not in possible syntactic or word-finding difficulties, we focused on the patients' single word repetition. The same task will be used later for our experimental investigation. We carried out analyses that looked at the presence of phonetic errors and analyses of the speed of utterances. We expected both measures to reflect difficulties with articulatory programming.

Phonetic errors. To compute the rate of phonetic errors, we listened (and re-listened) to the taped single word repetition of the patients. 773 words were repeated by each patient (a more detailed description follows). However, some recordings were carried out with a tape-recorder rather than with a mini-disk and their quality was not good enough to allow subtle phonetic analyses. Because of this, the corpus of analysed words is different in different patients. The number of words analysed for each patient, however, is always large enough to allow a good estimate of the rate of phonetic errors. The errors were scored by both authors. The first author was blind to the patient identity and classification. Disagreements were resolved by discussion and by re-listening to the tapes.

We considered phonetic errors:

a) slurred phonemes where the target was recognizable, but produced in an imprecise fashion;
b) phonemes produced with an audible effort;
c) phonemes that were difficult to categorize because they were ambiguous between two possible targets (e.g., /p/-/b/ ; /s/-/z/) or because they were not part of the Italian inventory (e.g., aspirated consonants; schwa vowels).

Note that this and later analyses were carried out on individual phonemes so that more than one error could be made on the same word.

## Articulatory speed

We used spectrographic analyses to measure word durations. From the corpus of words repeated by each patient we selected 25 words repeated correctly and 18 words which contained a single phonological error (e.g., a phoneme substitution, deletion, insertion or transposition; all patients had at least 18 responses of this type). As in the analyses described later the first response of the patient was considered. The words produced correctly were matched across patients for length, frequency and syllabic complexity. The same matching was not possible for the words produced incorrectly since some patients did not make very many errors of the type considered. However, the errors were matched for whether they resulted in a syllabic simplification, a syllabic complication or had a neutral outcome (see later for more detail). The error corpus of each patient included eight simplifications, eight complications and two neutral errors.

All the words in the corpora of all the patients were repeated by three neurologically intact, Italian native speakers. To ensure that there was no systematic variation in the speed with which the three normal speakers repeated the words of the different patients, the order of words (from al the patients) was randomized.

## Results

All patients made some phonetic errors that, we assume, are almost never made by normal speakers and all of them showed some indication of reduced speech rate. There were, however, large variations across patients as well as a lack of agreement between our two production measures. This prompted a reclassification of the patients into four groups. Results are reported in Table 2.

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Insert Table 2 about here

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Rate of phonetic errors reflected the clinical classification into fluent and dysfluent patients, with the dysfluent patients all making a sizeable number of errors (between 12.3% and 24.0%) and the fluent patients showing much lower rates (between 0.5% and 4.1%). The difference between the two groups was highly significant (t= 7.7; p<.001).

Slow speech was due to both intersyllabic pauses and to elongations of consonants and vowels. All patients were slow compared to the average of the three controls both when they produced correct responses (t= 2.5-9.2; p<.001-<.01) and when they produced errors (t=2.2-12.3; p<.001-.<05). Patients originally classified as disfluent were generally faster than those originally classified as fluent, however, MC (originally classified as fluent) was very slow and AP (originally classified as disfluent) was relatively fast.

We classified as 'slurred' AV and AP who made a high rate of phonetic errors, but had articulatory speed in the range of other fluent patients. In addition, they never produced speech with audible effort and made a higher proportion of slurred responses (rate of slurred responses among phonetic errors in AV: 89%; AP: 43%; in other dysfluent patients, EM: 17%; MI: 9%; DG: 36%; DC: 24%; GC: 23%). AV and AP may suffer from a more peripheral articulatory impairment that affects speech realization rather than articulatory programming. We classified as 'slow' MC, who showed the opposite pattern with a low proportion of phonetic errors, but very slow speech production. Production had marked and consistent inter-syllabic pauses and frequent false starts (e.g., (e.g., 'attitudine' > /atti/.. attituni.. attitunide/; 'olimpiade' > /o/.. /o/.. /im.pi.la/…/oim.pi.l/ .../o.im.pi.de/… /o.im.pi.de/ … /o.im.pi.di.le/). Clinical notes reported that MC's speech had a jargonaphasic quality in the initial phases of his illness.[2] The remaining patients were classified as either apraxic (high rate of phonetic errors and with a slow speech) or fluent (phonological but not phonetic errors and relatively fast speech). The speech of the fluent patient was significantly faster than the apraxic patients; considering the average of correct and incorrect responses: t= 4.4; p<005). For the purpose of some later analyses we will consider both the apraxic and the slurred patients to suffer from some kind of articulatory impairment, while we will consider the fluent patients and the slow patient to suffer from a more central phonological impairment.

## Background Neuropsychological Testing

All patients were given an Italian Battery for the Assessment of Deficits in Aphasia (BADA; Miceli, Laudanna, Burani & Capasso, 1994) which includes tests of reading, picture naming, spelling to dictation, word comprehension and sentence-picture matching. They were all untimed tasks. Description of tasks and corresponding results are presented in Appendixes 2 and 3. Results in tasks tapping bucco-facial apraxia and phonological input processing which are most relevant to our experimental investigation are presented next.

Bucco-facial apraxia. All patients were given a test of bucco-facial apraxia. They were required to imitate ten gestures (e.g., show your tongue, whistle, yawn etc). Two points were given for each perfectly imitated gesture; one point was given for a second correct attempt; 0 points were given for an incorrect or imprecise gesture. With the exception of DC, all of the patients with articulatory difficulties were impaired. MC and all of the fluent patients performed normally (see

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[2] RM was quite slow in producing words containing an error. Arguably, however, one should give more weight to the analyses where words are produced correctly. Different factors may slow down the productions of words repeated incorrectly. For example, speed of articulation may be affected by a realization that an error has been made or is about to be made.

Table 3). These results are consistent with previous results indicating that many patients with apraxia of speech exhibit non-verbal oral apraxia even if either deficit can also be present in the absence of the other (see Duffy, 1995, page 126; De Renzi, Pieczuro and Vignolo, 1966; Mateer & Kimura, 1977).

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Insert Table 3 about here

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Phonological discrimination. Phonological input processing was assessed with four tasks. The first three were discrimination tasks where the patient could indicate his response by either a spoken reply (e.g., yes/no, same/different), a gesture, or by pointing to a smiley/sad face. The fourth was a matching task.

1) Same/different syllable discrimination. Two syllables were spoken by the examiner with about a one second pause in between. The patient had to indicate whether they were the same or different. The syllables were made up by a stop consonant (/t/, /d/, /p/, b/, /k/, /g/) followed by the vowel /a/. In half of the trials the syllables were the same; in other half they were different. All possible consonant combinations were used.
2) Same/different word discrimination. The task was the same as the one above except that real words and matched nonwords were used. They were paired either with the same word/nonword or with a foil constructed by changing a single consonant in different positions (beginning, middle or end of the item).
3) Lexical Decision. The experimenter read a list of spoken words mixed with an equal number of made-up words. The non-words were constructed by using a second matched set of real words with a single phoneme changed. The patients had to indicate whether or not each stimulus was an existing Italian word.
4) Word comprehension. This task required a spoken word to be matched with one of two pictures. For a fuller description see Appendix 2. What is relevant here are the trials where a spoken word has to be matched to one of two phonologically related pictures (e.g.: treccia (braid) - freccia (arrow)).

Results are presented in Table 4. Most patients performed very well on all tasks. MP did not perform well on the lexical decision task, but performed well on the other three tasks. EM And

MC are more problematic. EM did not carry out the discrimination tasks since he was unable to consistently make a yes/no decision. MC performed poorly in two out of four tasks. We felt, however, that neither of them suffered from a significant discrimination problem.

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Insert Table 4 about here

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First of all, in a task which did not involve a yes/no decision (word comprehension) EM performed well, making only 2/20 errors. Equally, MC performed well on the two tasks which required phonological discrimination but not lexical access. Also, the nature of the repetition performance of the two patients did not suggest a phonological input problem. They rarely asked for repetitions of the target and their errors were very rarely phonologically related words (for EM: 4.1%; for MC: 7.0%). Moreover, EM's repetition errors were restricted to consonants (928 errors on consonants and 15 on vowels). Although vowels are perceptually more salient, it seems unlikely that a discrimination deficit would produce such a dramatic dissociation. Instead, selective problems with either consonants or vowels have been reported in patients with production difficulties (e.g., Caramazza, Chialant, Capasso & Miceli, 2000). Finally, MC showed very similar error patterns in repetition and in reading aloud where there is no phonological input (see Table 9 later on). Given these considerations, we feel confident that even if EM and MC suffered from a mild phonological discrimination problem, it had no significant impact on their repetition performance.

## Experimental Task

### Stimuli and procedure

Our experimental task involved the immediate repetition of single words spoken by the examiner. It included 773 words from various lists testing effects of frequency, imageability, grammatical class, phonological length, and complexity. Frequency was measured according to the Barcellona Corpus (1988) which contains 1,500,000 words and incorporates Bortolini, Tavaglini and Zampolli (1972). Concreteness ratings were provided by four Italian native speakers who rated words on a 0-1-2 scale (with 0=abstract and 2=very concrete). Stress was classified as regular or irregular. Monosyllabic words and words with stress falling on the penultimate syllable were considered regular. All other words were considered irregular (see also Colombo, 1992). Words with odd sonority clusters were generally avoided in our corpus.

Complexity was measured in the following way:

a) We assigned one complexity point to complex onsets, codas, and hiatuses.

b) We assigned two complexity points to complex onsets in word initial position preceded by /s/ (e.g., /stra/, /spya/). Complex codas are very rare in Italian. There was only one in our corpus (‘film’), which was also assigned two complexity points.

c) We have assigned half a complexity point to simple onsets consisting of a glide (e.g., /wa/, /ya/ etc.), to geminates (e.g., al.lora), and to single vowel syllables in word initial position (e.g., an.dare).

In Italian, sequences of high vowels (i,u) followed by other vowels could be either hiatuses, if they are pronounced as full vowels (e.g., pa.net.ter**i.a** [bakery], since the stress is on /i/, by definition this vowel cannot be reduced) or more commonly they are diphtongs where the vowel is produced as a glide (/y/, /w/, also called semiconsonants). Rising diptongs, where the glide precedes the vowel (a.**yu**.to [help]), contrast with falling dipthongs, where the glide follows the vowel (**aw**.li.co [poetic]). There is general consensus that the glide of a rising dipthong should be part of the onset. This could be either a simple onset as in /**wo**.mo/ [man]; or a complex onset as in /**pya**n.ta/ [plant]). Since there is general consensus on the complexity of dipthongs (Bernhardt & Stemberger, 1998; Stemberger, 1990) and since these are the most complex simple onsets in Italian according to the Sonority Dispersion Principle (see later), we have assigned them half a complexity point. We have assigned two complexity points to complex onsets containing a glide (e.g., pya.no [show]) as we have done for other complex onsets.

How to classify falling diphtongs is more ambiguous. We have decided to group them with hiatuses since there is little evidence, at least in Italian, of any difference in production (Marotta, 1988; Burani & Cafiero, 1991). Thus we have assigned them two complexity points.

Italian phonology includes geminate consonants which carry contrastive meanings (e.g., compare, ‘calo’ [to lower 1st person] vs. ‘callo’ [callous]; ‘mo.to’ [scooter] vs. ‘mot.to’ [saying]). There is evidence that geminates are like heterosyllabic clusters with one consonant in coda and one in the onset of the following syllable. However, there is also evidence that geminates, where point of articulation stays the same, are easier than heterosyllabic clusters, where the point of articulation has to change. For example, Italian children often reduce heterosyllabic clusters to geminates. Young English-speaking children also reduce intervocalic clusters to geminates, even though

English lacks geminates (see Bernhardt & Stemberger, 1998). Given these considerations, we have assigned half a complexity point to geminates.

The complexity of single vowel syllables in word initial position is unclear. On the one hand, an onsetless syllable represents a transformation of what we have argued is the basic CV template. On the other hand, constraints which work in the body of the word often do not apply at the periphery. Onsetless syllables could be an example. Following the Sonority Dispersion Principle (see later) the CV template is optimal because sharp alternations of low and high sonority segments are optimal. However, at the periphery of the word, the sonority of the vowel just has to contrast with silence. In these conditions, there may be less difference between a V or a CV syllable. Given these considerations, we assigned half a complexity point to vowels in word initial position. Instead, we have assigned 2 complexity points to single vowel syllables in the body of the word (which involve a hiatus; see also McCarthy & Prince, 1993).

Complexity points were assigned disregarding the position of the structure in the words (e.g., whether it was in the first syllable or in any other syllable of the word). Complexity for a word was the sum of its individual syllabic complexities. The distribution of words of different lengths and degrees of complexity across the whole corpus is shown in Table 5. Length and complexity are more orthogonally distributed in our corpus than in N & H's. The great majority of words are distributed over six lengths (between 4 and 10 phonemes) and four levels of complexity (between 0 and 4 degrees of complexity, with half points in between). There are variations in complexity among words of the same length and variations in length among words of the same complexity.

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Insert Table 5 about here

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All repetition was taped to allow rechecking. For scoring purposes we used the first response given by the patients. False starts and fragments were considered errors even if followed by a correct response. For the purpose of the following analyses, words produced with an articulatory effort or in a slow or syllabified manner were considered correct as long as the right phonemes were produced in the right order. Overall proportion correct for the various patients is reported in Figure 1.

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Insert Figure 1 about here

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## Complexity as a predictor of correct performance

Like Nickels and Howard, we used binary logistic regression analyses to assess the ability of various variables to predict correct repetition. Our general expectation is that words of lower complexity, higher frequency, lower phoneme or syllable length, higher concreteness and regular stress pattern will be repeated better than their respective counterparts.

Group analyses. We carried out two group analyses using patients with articulatory difficulties in one group and MC and the fluent patients in the other. The variable 'patient' was entered first. All the other variables (frequency, concreteness, phoneme length, syllable length, stress and complexity) were entered together in the second step.

In this and subsequent analyses all the effects are in the expected direction. Complexity was highly significant for the articulatory group, but not for the phonological group (wald= 39.7; p=<.001 versus wald=0.1; p=.75). Both groups showed significant effects of frequency (wald = 23.5 and 15.8; for both, p=<.001) and length (wald = 98.3 and 63.2; for both, p<.001). In addition the phonological group showed an effect of concreteness (wald=6.3; p=.01) not significant in the articulatory group (wald 1.7; p=.19). This is consistent with the fact that the fluent patients have a more central locus of impairment: words higher in concreteness may have richer semantic representations which activate more strongly the corresponding lexical representations. The articulatory patients may show frequency effect as the phonological patients because words higher frequency words better support the activation of the corresponding representations during both phonological encoding and articulatory programming. Neither groups showed an effect of stress (articulatory group: wald= 0.5; p=.49; phonological group: wald= 2.0; p=.16).

Individual analyses. We also carried out analyses of individual patients. Two types of analyses were carried out. In the first, all our variables were given an equal opportunity to explain variability (method Forward likelihood ratio). In the second type of analyses, complexity was entered alone in a second block, after frequency, concreteness, phoneme length, syllable length and stress were taken into account. This second set of analyses clearly disadvantages complexity and shows whether it still makes a significant contribution after all other variables have been considered. Results are reported in Table 6.

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Insert Table 6 about here

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Four of the patients classified as apraxic and one of the patients classified as slurred showed significant effects of complexity when the effects of other variables, and most crucially phoneme length, were simultaneously taken into account. The only apraxic patient who failed to show a significant effect was DC. This is unsurprising since DC is the most severe patient in the group and makes very few correct responses. Analyses on matched lists and error analyses reported later will show consistent effects of complexity in DC. Among patients with slurred speech AV, but not AP, showed a significant effect of complexity. In contrast, MC and none of the fluent patients showed significant effects of this variable. When complexity was entered last in the regression equation, it continued to be significant or to approach significance in all of the apraxic patients while it failed to be significant in all the other patients.

Our results contradict those of N & H and show clear effects of complexity that cannot be explained by phoneme length. In addition, significant effects of complexity were shown only in patients with articulatory difficulties. These results are consistent with the hypothesis of a link between syllabic complexity and articulatory difficulties (see Romani et al., 2002, for the same hypothesis and additional, consistent results). This link supports our confidence in the reality of complexity effects and in the metric of complexity we used.

<u>Analyses using complexity as numbers of complex onsets</u>. Our analyses do not explain the null results of N & H since three of their patients showed signs of apraxia of speech with two of them having apraxia of speech as their primary deficit. One possibility, as we have noted, is that their null results are due to the use of a more restricted metric of complexity. If this is the case, we should also find no effects when we measure complexity in their way: using the number of intra-syllabic clusters. In Italian, this restricts the analysis to complex onsets given the rarity of complex codas. Thus, we carried out the same logistic regression analyses describe before except that we used number of complex onsets instead of our previous measure of syllabic complexity.

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Insert Table 7 about here

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Number of complex onsets was a significant predictor of performance in five patients with articulatory difficulties, when the contribution of other variables was simultaneously taken into consideration. Moreover, in several patients, it continued to be a significant predictor of performance even when it was entered last, after all the other variables. Significant results were shown by four of the articulatory patients, by MC, and by one fluent patient. Again, these results are very different from those of N & H even if they less neatly distinguish the apraxic patients from the other groups.

Our results showing that performance on complex onsets does not sharply distinguish between groups of patients is consistent with previous research showing more deletions in complex onsets than in other structures across clinical classifications (e.g., Blumstein, 1978; Romani et al., 2002). All aphasic patients avoid deletions of simple onsets. If the onset is preceded by a vowel, a deletion would result in a hiatus, a structure whose complexity is undisputed (e.g., ta.vo.lo > ta.o.lo). If the onset is preceded by another consonant (as in the case of a hetero-syllabic cluster; e.g., al.pi.no) deleting the onset would involve re-syllabification (al.pi.no> a.li.no; the /l/ originally in coda has to be reassigned to the onset of the following syllable). In this context, our patients almost invariably delete the coda rather than the onset, arguably to avoid resyllabification (e.g., /al.pine/> /a.pine/ not /a.line/). It is possible that a tendency to avoid complex restructuring of the target is responsible for more errors on words containing complex onsets across patients. Consistent with this interpretation, Paradis and Beland (2002) have shown that aphasic patients and children avoid errors which eliminate complex structures, but which involve either a high processing load in term of the steps necessary to modify the target and/or an increase in the metrical complexity of the target (see also Dell, Juliano & Govindjee, 1993 for related claims about the tendency of normal speakers to avoid errors which violate phonotactic constraints).

<u>Conclusion.</u> Using a more comprehensive measure, our analyses showed significant and consistent effects of syllabic complexity in a group of apraxic patients, but not in fluent patients. Using the same measure as N & H (number of complex onsets), we also obtained significant effects of complexity, although this measure did not as neatly distinguish the apraxic from the fluent patients. This is consistent with previous research which has shown that patients of all clinical

classifications make more deletions on words with complex onsets (Blumstein, 1978; Romani et al., 2002).

Our results do not provide a definite answer as to why N & H did not find complexity effects. A concurrence of causes is likely. One main cause is likely to be the set of stimuli they used. Length varied more than complexity and complexity was often confounded with length. This favoured the emergence of effects of length over complexity in a group of patients who were, in the first place, selected because they showed length effects in picture naming. It is important to stress that N &H did exclude from their analyses one patient who showed no length effect but a clear tendency to simplify complex clusters. Their analyses, therefore, were clearly biased in favour of finding null effects. More theoretical arguments for N & H’s lack of positive results will be presented in the General Discussion.

The next section will provide evidence for effects of complexity using a subset of stimuli where complex and simple words are contrasted, but phoneme length and other variables are closely matched. We expect the same patients who showed complexity effects in the regression analyses to show complexity effects in these further analyses.

## Effects of complexity with matched lists

Following a well established approach in neuropsychology, we have contrasted words with simple and complex structures while controlling for word frequency, concreteness, grammatical class and, crucially, phoneme length. N & H did not use lists of this type. One reason might have been that it was not possible to simultaneously match for phoneme length, syllable length and complexity. Words can be selected so that they are matched in phoneme length and differ in complexity, but simpler words will tend to have more syllables than the complex words. This, however, is not a problem since syllable length and complexity work in opposite directions. In all our patients, including those who showed a significant and independent effect of syllable length, words with more syllables led to worse performance than words with fewer syllables. Thus, if simple words lead to better performance than complex words, they do so against what would be predicted by syllable length.

Table 8 shows the relevant statistics for our complexity list and, for the frequency list and length list for comparison.

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Insert Table 8 about here

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Results. Figure 2 shows the results for the three lists contrasting complexity, frequency and length. A significant effect of frequency was shown by three of the patients with articulatory difficulties (DC: $\chi^2(1)=6.2$; $p=.01$; AV: $\chi^2(1)=8.5$; $p=.003$; and AP: $\chi^2(1) =5.080$; $p=.02$) and by three of the fluent patients (MP: $\chi^2(1)=3.1$; $p=.08$; AC: $\chi^2 (1) =13.312$; $p<.001$; and RM: $\chi^2 (1)=9.2$; $p=.002$). A significant effect of phoneme length was also shown by three of the patients with articulatory difficulties (DG: $\chi^2 (1) =9.7$; $p=.002$; MI: $\chi^2 (1) =12.1$; $p<.001$; and AV: $\chi^2 (1) =8.5$; $p=.003$) and by three of the phonological patients (MC: $\chi^2 (1)=6.1$; $p=.01$; RM: $\chi^2 (1) =5.1$; $p=.03$; and GM: $\chi^2 (1)=10.2$; $p=.001$). Most crucially, however, an effect of complexity was shown by all four of the apraxic patients (EM: $\chi^2 (1) =6.9$; $p=.01$; DG: $\chi^2 (1) =3.6$; $p=.08$; MI: $\chi^2 (1) =4.0$; $p=.05$, GC: $\chi^2 (1) =9.4$; $p<.001$), but by none of the phonological patients.

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Insert Figure 2 about here

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## Complexity in terms of errors: Do they simplify the target?

It is important to show that the influence of complexity can be seen not only in analyses of correct and incorrect performance, but also in analyses of the types of errors patients make when they are wrong. Our expectation is that those patients whose correct performance is affected by the complexity of the target will be the same ones who show a tendency to simplify in their errors.

A breakdown of the errors for the various patients is shown in Appendix 4. All of the patients made mostly errors which resulted in nonwords (average 88.4%; range 98-65%). Only three of the fluent patients (TC, MP and AC) made a sizeable number of word errors. These were generally morphologically related to the target. Among nonword errors, the majority could be scored as no more than three individual phonemic transformations such as deletions, substitutions, insertions and transpositions of phonemes (average = 71%; SD=19.4; range: 35%-96%). These errors that we called single phoneme errors were also the most common error type among all errors for most patients (average = 64.0%; SD=18.7; range: 31.5%-93.0%). [3]

Single phoneme errors were individually analysed to see whether they resulted in a structure which was less complex, as complex, or more complex than the target. For these analyses, therefore, a single target word contributed more than once if it contained more than one individual error. The numbers of analyzed errors for each patient were: DC=495; EM=937; DC=428; MI=379; GC=330; AV=451; AP=190; MC=714; TC=149; MP= 127; AC=140; RM=117; GM=132.

According to the principles outlined in the Introduction, we considered simplifications:

a) Errors which eliminated complex onsets (e.g., deletions: /**sta**.bilito/ > /**sa**.bilito/; insertions: /**kli**.ente/ > /**ki.li**.ente), and codas (e.g., deletions: /**pol**.verosa/ > /**po**.lerosa/ ; insertions: /**bron**.tolone/ > /**bro.no**.tolone/).

b) Errors which eliminated hiatuses (e.g., deletions: /usufr**u.i.**re/ > /usufr**i**.**re**/; insertions: p**o**.**e.**ta/>/po.**le**.ta/), and single vowel syllables in word initial position (e.g, deletions.: /**e**.roe/ > /roe/; insertions: /**i.**sola/ > /**ri**.cola/).

c) Substitutions which produced a steeper sonority profile in the onset of the syllable and a flatter profile in the coda of the syllable. Thus, consonant substitutions which decreased sonority in onset (e.g., /**b**ur.ro/ > /**p**ur.ro/) and increased sonority in coda (e.g., ‘/fe**s**.ta/ > /fe**r**.ta/ ).

d) Errors involving geminates where a consonant cluster was assimilated to a geminate (/i**s.t**ituto/ > /i**t.t**ituto/) or a geminate was reduced to a singleton (e.g., /**pat.t**o/ > /**pa**.**t**o/; see note 1).

e) A few transposition errors which changed the overall complexity of the target (e.g., /rom.bo/ > /om.bro/).

We considered complications the opposite types of errors (see also Romani et al., 2002). Neutral errors included: a) vowel substitutions since vowels may all be relatively easy to articulate (see later for an explanation); and b) consonant substitutions which did not change sonority (e.g., /t/>/p/ or /p/>/t/); c) most transpositions (e.g., /pulpito/ > /pultipo/). Results are reported in Figure 3.

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[3] The exceptions are RM, a mildly impaired patient, where the most common error consisted of a fragment (either correct or incorrect) followed by a correct response and DC, the most severe patient in the group, who made more errors involving multiple phonemes.

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Insert Figure 3 about here

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The apraxic patients show a very clear tendency to simplify. In this group, all patients make significantly more simplifications than complications (DC: $\chi^2$ (1)=15.6; p<.001; EM: $\chi^2$ (1)=110.4; p<.001; DG: $\chi^2$ (1)=10.0; p<.001; MI: $\chi^2$ (1)=52.4; p<.001; and GC: $\chi^2$ (1)=17.5; p<.001). In striking contrast, simplification and complication rates are very similar among all the fluent patients (TC: $\chi^2$(1)=0.6; p=.80; MP: $\chi^2$(1)=0.4; p=.53, AC: $\chi^2$ (1)=0.2; p=.67; RM: $\chi^2$(1)=0.3; p=.57; GM: $\chi^2$(1)=1.0; p=.32). Among the other patients, AP makes significantly more simplification than complication errors ($\chi^2$(1)=17.5; p<.001) like the other patients with articulatory difficulties. AV shows no significant difference ($\chi^2$(1)=2.14; p=.14). MC shows no tendency to simplify like the other fluent patients ($\chi^2$(1)=1.2; p=.28).

AV is the only articulatory patient who shows no tendency to simplify. However, her high rate of complications is due to a preference for initiating speech with an open sound. Thus, she deletes simple onset consonants in word initial position (e.g., ‘tuta’ > /uta/; ‘pellicola’ > ‘ellipola’; ‘naftalina’ > /affitalina/; N=89), but not in other positions (N=3). For consistency, we have classified these errors as complications since they produce single vowel syllables. We wonder, however, whether they are just another manifestation of AV’s articulatory deficit (see Paradis & Beland, 2002 for similar results in normal children). AV would show a clear simplification tendency if these errors were not considered (58% simplifications; 21% complications and 21% neutral errors).

A similar simplification pattern was found when we looked at phonological errors that are more distant from the target so that they are not easily decomposed into a number of individual phoneme changes. Most patients made only very few of these errors. However, two of the apraxic patients and MC made a sizeable number (DC=347; EM=172; MC=130). For each patient, we computed a mean complexity score for targets and errors according to the complexity metric described above for the analyses of correct and incorrect responses. In both of the apraxic patients, the errors were significantly less complex than their targets: DC: target = 1.4; error = 1.1 (t=6.2; p.00); EM: target =1.8; error = 0.8 (t=14.6; p =.00). While no significant tendency was found in MC (target = 1.7; error = 1.6; t=1.7; p=.10).

Vowel markedness. In the analyses above, we have not considered vowel markedness. There is, however, general agreement that low vowels (e.g. /a/) are more sonorous and less marked than mid vowels (/e/ and /o/) which in turn are more sonorous and less marked than high vowels (/i/ and /u/; e.g., see Prince & Smolensky, 1993). In addition, one could argue that more sonorous vowels will optimize the sonority profile of the syllable by increasing differences with the margins. Of the 105 vowel substitutions made overall by the articulatory patients 40 (**38%)** increased sonority, 41 (**39%)** decreased sonority and 24 (**23%)** were neutral. Of the 124 substitutions made overall by the phonological group, 51 (**41%)** increased sonority, 40 (**32%)** decreased it and 33 (**27%)** were neutral. There was no difference in the rate of errors increasing or decreasing sonority for either group ($\chi^2(1)=.006$; p=.94; $\chi^2(1)=0.7$; p=.41, respectively). Our interpretation of these findings is that vowels are articulatorily easy relative to consonants. Consistent with this claim the articulatory group made very few errors on vowels. On average, 94% of their errors were on consonants and only 6% on vowels (% of consonant errors: range= 89-99; SD=3). It is possible, therefore, that the errors made on vowels were mostly selection errors (like those produced by the phonological group), and, thus, insensitive to effects of complexity (the phonological patients made only slightly more vowel errors: 83% of errors on average were on consonants, range 64-99, SD=14). DB, the patient studied by Romani & Calabrese (1998) also showed no sonority/markedness effects in his vowel errors, despite a general tendency to simplify.

## Comparison between repetition and reading

If our patients are, indeed, impaired in the mechanisms which produce speech after lexical access has been accomplished, they should show the same pattern of errors in other production tasks. We have compared the errors made by two patients in repetition and reading. We chose two patients that differed in their tendency to simplify: GC and MC. GC was chosen because he made no errors in reading the small list of words given in the general neuropsychological assessment. Therefore, it was important to ascertain that he would indeed make errors when a longer list of words with more varied stimuli was administered. MC was chosen because he showed mild difficulties in tasks assessing phonological input. Thus, it was important to establish that the same production pattern occurred in a task that had no phonological input.

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Insert Table 9 about here

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Results are reported in Table 9. The pattern shown by each patient across the two tasks is very similar. Most crucially, however, GC showed a simplification pattern both in repetition and in reading. The difference between the number of simplifications and complications was significant in both tasks (repetition: $\chi^2(1)=90.0$; $p<.001$; reading: $\chi^2(1)=50.7$; $p<.001$). Instead, there was no difference in the rate of complications and simplifications in MC in both tasks (repetition: $\chi^2(1)=1.9$; $p=.17$; reading: $\chi^2(1)=1.2$; $p=.27$). These results support our interpretation that our patients suffer from a production impairment which is consistent across tasks, although the nature of the deficit is different in different patients.

Analyses of complexity in contextual errors

We have reported clear complexity effects in the single word production of aphasic speakers. Our results contrast with the surprising results reported by Stemberger and colleagues that errors produced in spontaneous speech and in experimental tasks by normal speakers result in more complications than simplifications (Stemberger, 1990; 1991; Stemberger & Treisman, 1986). This difference, however, may be due to the larger number of contextual errors in normal speech error corpora.

Aphasic patients make errors in the production of isolated words (word repetition, word reading, picture naming); normal speakers do not make errors in these tasks, but they do make errors in the production of connected spontaneous speech and in experimental situations where they are asked to produce strings of words devised to elicit errors. In these conditions, the majority of the errors produced are contextual. These are errors where segments are either anticipated or perseverated in the utterance (generally between content words in close proximity to one another). Contextual errors show a predominance of complications, while non-contextual errors are generally simplificatory (see Stemberger, 1991, 1992). Since the majority of the errors made by normal speakers are contextual, the overall pattern shows a tendency to complicate structures (e.g., create complex from simple onsets).

A few studies have looked at the contextual errors made by aphasic patients in either spontaneous speech (Blumstein, 1973; Kohn & Smith, 1990; Schwarz, Saffran, Bloch & Dell, 1994) or in single word production (Lecours & Lhermitte, 1969; Miller & Ellis, 1987), but none has examined complexity effects. Given the opposite associations shown by contextual and non-contextual errors in normal speakers, one could envisage that differences in the rate of contextual errors could also mediate differences in rates of simplifications in aphasic patients. Suppose that our phonological group makes more contextual errors than our articulatory group; this could predict the respective rates of simplifications rather than differences in articulatory skills. To test this possibility we have looked at the contextual errors made by our two groups of patients and at a tendency to simplify within these errors.

Method. We have looked at the rate of anticipations and perseverations in our patients' repetition. Given the nature of the task, all our contextual errors are within word. We have considered contextual errors both substitutions and insertions which anticipate or perseverate segments occurring elsewhere in the word. Following others (e.g., Miller & Ellis, 1987; Kohn & Smith, 1990), we have calculated a baseline level of contextual errors by using pseudo-corpora of errors constructed by randomly reassigning the real errors to new targets. We have made the pseudo-errors respect the same constraints as the original errors by creating them in the same word position as the original errors, by substituting consonants with consonants and vowels with vowels, and by making the new errors respect the phonotactic constraints of Italian. Three pseudo- error corpora have been created by reshuffling errors and targets three times. Mean rates of contextual errors on the combined pseudo-corpora have been used for comparison with rates of contextual errors in the real/observed corpus.

Results. Results are reported in Table 10. The rate of contextual errors was higher in the articulatory than in the phonological group of patients (29% vs. 23% respectively; percentages calculated over total number of substitution and insertion errors; $\chi^2(1)=87.7$; $p<.001$). Moreover, only in the articulatory group, was the rate of contextual errors significantly different from chance (articulatory group: $\chi^2(1)=87.7$; $p<.001$; phonological group: $\chi^2(1)=0.5$; $p=.48$). This was true both for anticipations ($\chi^2(1)=9.6$; $p=.001$) and perseverations ($\chi^2(1)=10.3$; $p=.001$), while neither type of error was significantly different from chance in the phonological group (anticipations $\chi^2(1)=0.2$; $p=.88$; perseverations: $\chi^2(1)=1.1$; $p=.30$). Within contextual errors, the articulatory group showed the same significant tendency to simplify shown in the overall corpus (rate of simplifications 252/544= **46**% vs. rate of complications 172/544=**32**%; $\chi^2(1)=7.1$; $p=.006$); while the tendency of the phonological group was in the opposite direction (simplifications: 49/218= **22**% vs. complications 93/218=**43**%; $\chi^2(1)=6.8$; $p=.008$). This is due to the over-representation in this subset of errors of insertions which generally result in complications [4].

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[4] Note that the articulatory patients made more anticipations than perseverations (17.3% vs. 11.4%; $\chi^2(1)=26.0$; $p<.001$); while this was not true for the phonological patients (10.9% vs. 11.3%). This is possibly due to the fact that the articulatory patients had more problems with

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Insert Table 10 about here

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Our results do not support the hypothesis that the different simplification rates in our groups of patients are due to different rates of contextual errors. Differently from what has been found in normal speakers, the articulatory group makes both more contextual errors and more simplifications. Moreover, the pattern of simplifications is the same in the contextual errors as in the overall corpus.

One possibility is that the different pattern found in normal and aphasic speakers is related to task differences. According to this explanation, within-word contextual errors (collected in single word production) have different characteristics than between word contextual errors (collected in the production of word sequences). Perhaps within-word errors (whether contextual or not) reflect difficulties in the phonological encoding and/or articulatory realization of words, while between-word errors reflect ordering difficulties arising when several words are kept active in a production buffer. This would explain why between-word errors are not subject to complexity effect, while at least a subset of within-word errors are. According to this explanation, true between-word errors collected in the spontaneous speech of aphasic patients should not show any complexity effect (or show an inverse complexity effect) as is found in normal speakers.

## Consistency between different measures of complexity

We have shown complexity effects with a variety of analyses and using different measures. In the analyses which looked at complexity as a predictor of accurate repetition, we have used two measures. One was number of complex intrasyllabic clusters, which in Italian is equivalent to complex onsets. This is the same as the measure used by N&H with the limitation that Italian does not have complex intra-syllabic clusters in coda. The second one was a more comprehensive measure where we considered a complication any modification of the most simple CV template. For clarity, we will refer to this measure as template complexity. The same measure of template complexity was used in our analyses of matched lists. In our error analyses, however, we have combined two measures: one was our index of template complexity, the other was a measure of how optimal the sonority profile of the syllable was. Following the sonority dispersion principle

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speech initiation.

(Clements, 1990), we considered to be simplifications errors which made sonority increase maximally in onset and minimally in coda.

There are good theoretical and empirical reasons to assume a high concordance between the different measures of complexity we used. First of all, as mentioned, it is reasonable to expect that a patient who is better able to produce simple than complex words, will show a tendency to simplify in his errors. The very ‘purpose’ of the errors, in fact, could be to make the string pronounceable. Secondly, one would assume that measures of complexity in terms of number of units in the CV template and in terms of sonority profile should go hand in hand. The same type of distributional evidence has motivated the ranking of syllable templates and the sonority dispersion principle. One could believe that constraints on template complexity and sonority complexity are abstract and have separate representations in Universal Grammar. According to this approach, these two measures could be unrelated. Another approach, however, which is supported by our results, is to assume that both these constraints have a physiological basis so that the structures which have a wider distribution are those which are easier to perceive and/or to produce. According to this approach, less marked structures would be less problematic for patients with articulatory difficulties whether complexity is defined in terms of CV sequences or sonority profiles. Equally, patients should find all different types of structures which complicate CV templates problematic. Although selective difficulties may be envisioned, all in all, one would expect a high co-occurrence between difficulties with different types of complex structures. First of all, it is unclear whether these different structures imply different kinds of articulatory skills, secondly, even if they do, one would expect that brain damage will generally affect a variety of articulatory skills since they are likely to be represented in nearby neuronal populations.

Concordance between accuracy rates and direction of errors. To assess the concordance between effects of complexity on accurate performance and simplifications in the errors we have looked at the correlation between the coefficients associated with complexity in the regression equation predicting accuracy and % of errors which resulted in simplifications. There was a highly significant correlation (when complexity was entered first in the regression equation: Pearson r=.77; p=.002; when complexity was entered last and Pearson r= 76; p=.003).

Concordance between template complexity and sonority complexity. To assess the concordance between template complexity and sonority complexity, we looked at the correlations between simplifications of CV templates (deletions and insertions which reduce the complexity of the templates) and substitutions which optimize the sonority profile of the syllable. We considered rate of simplifications within error type since patients vary in the kinds of errors they make (generally, the articulatory patients make more deletions while the phonological patients make more substitutions). Simplifications in terms of CV template and in terms of sonority were inter-correlated (Pearson r = .63; p=.02) and they showed similar correlations with rate of phonetic errors (template: Pearson r = .62; p=.03; sonority: Pearson r = .72; p=.005) and with the ability of complexity to predict correct repetition (when complexity was entered first, template: Pearson r = .77; p=.002; sonority: Pearson r = .61; p=.03). These results support the claim that both measures are linked to articulatory difficulties. In fact, the overall measure of simplifications (which combines template and sonority simplifications) was even more strongly linked to rate of phonetic errors than the individual measures (Pearson r=.83; p=.001; although the difference with the individual-measure correlations did not reach significance; t (10) = .60 and t (10) = 1.14). It is important to note that these correlations are not spuriously related to the different severity of the patients. There were, in fact, no significant correlations between number of phonological errors and either overall simplification rate (Pearson r=.43; p=.13) or rate of phonetic errors (Pearson r=.47; p=.10).

Concordance between different kids of template simplifications. We further decomposed our measure of template simplifications into the following:

1. Simplifications of complex onsets
2. Simplifications of codas
3. Simplifications of single vowel syllables (word beginnings)
4. Simplifications of hiatuses
5. Simplifications of geminates into a singleton
6. Simplifications of clusters into geminates.

Table 11 reports number and rate of simplifications on these different structures. Table 12 reports the corresponding cross-correlations. Correlations are generally very high and significant with the exception of those involving hiatuses. However, given the low number of errors involving hiatuses, this result should be taken with caution and confirmed by further studies. With this one exception, our results support the claim that different types of template reduction are all manifestations of the same tendency to reduce syllabic templates to the most simple CV template.

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Insert Tables 11 and 12 about here

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## General Discussion

In the Introduction, we reviewed accumulating evidence of complexity effects in the errors of both children and aphasic speakers. In contrast, N & H have recently reported a lack of complexity effects when they analysed which variables predict accuracy in a group of nine aphasic patients selected on the basis of their making phonological errors in speech production and of their showing a length effect in picture naming. Our study addresses this inconsistency. One can envision four different reasons for N & H’s null results. We analyse them in turn.

Complexity affects the nature of the errors but not accuracy rates. This claim is counterintuitive. In the absence of empirical or theoretical motivation to the contrary, the simplest and most plausible hypothesis is that factors that affect accurate performance and the nature of the errors should go hand in hand. Both measures should indicate the relative difficulty that a patient has with different types of words. Thus, a patient who has difficulties with complex syllabic structures should produce fewer complex words correctly and, when an error is made, should produce simpler structures. The same logic has been applied when other variables have been investigated (e.g., a patient who is able to produce high frequency but not low frequency words correctly should also produce words of higher frequency when lexical substitutions are made). Consistent with these considerations, we have shown strong complexity effects in our group of patients both when the nature of the errors and when variables affecting correct performance have been considered. In addition, we have shown a correspondence between measures of correct performance and error analyses since the same patients whose correct performance is strongly influenced by complexity show a tendency to simplify in their errors.

Complexity effects could characterize the speech of certain patients but not others. N & H may have tested the wrong patients. Indeed, we have found consistent effects of complexity only among the apraxic patients. However, N & H included two patients with a main diagnosis of apraxia of speech. Moreover, using their same complexity measure (number of complex onsets), we found complexity effects across patient types consistent with previously reported error analyses (Blumstein, 1978; Romani et. al., 2002). Thus, this also does not seem the right explanation for the N & H null effects.

Complexity effects could be found in certain languages but not others. The lack of complexity effects in N & H's group of patients and the consistent presence of complexity effects in ours may be due to the different languages spoken by the two groups. There are some clear differences between Italian and English phonology. We have already mentioned that most English words end with closed syllables, while very few Italian words do. In addition, in English, consonants that follow stressed vowels (e.g., the /t/ in 'cottage') are believed to be ambisyllabic, that is, to belong to both the onset and to the coda of the preceding syllable. This adds to the general frequency of closed syllables in English. The ubiquity of codas in English contradicts the general rule that simpler syllables (thus, syllables without codas) should have a wider distribution both across languages and within languages.

While effects of syllabic frequency may attenuate complexity effects in the case of English codas, there is no reason to think that English would not otherwise be susceptible to Universal principles of complexity. That English is no exception is, in fact, demonstrated by reports of complexity effects in the errors of English children and aphasic patients (as described in the Introduction). In sum, it could be that complexity effects may be modulated by frequency effects in different languages and this may be an interesting topic of research. We have no reason to think, however, that complexity effects will be absent in some languages.

Complexity effects have not been given a fair chance to emerge. A final possibility, and the one we endorse, is that the lack of positive results in the N & H study was due to a number of methodological choices that severely restricted the possibility that complexity would emerge as a significant variable over and above phoneme length. First of all, N & H have chosen patients on the basis of their showing a length effect rather than a complexity effect. Secondly, they used a measure of complexity--number of complex onsets--which is confounded with length. Everything else being equal, a word with a complex onset will be longer than a word with a simple onset. Thirdly, they have chosen lists which are relatively insensitive in their ability to distinguish effects of complexity and length. By using patients selected just on the basis of their making phonological errors in their speech production, by using a better metric of complexity, and by using stimuli where variations in length and complexity were more similar, we got very different results showing strong, significant effects of complexity. These effects were found not only using regression analyses, but also using matched lists of words and in error analyses. The fact that they neatly distinguished the apraxic from the fluent patients further strengthens our confidence in the reality of the complexity effects.

The nature of complexity effect

We have found that complexity effects are associated with a specific stage in speech production, the one where articulatory programs are computed from a phonological representation. We have not found complexity effects in patients with more central phonological deficits. These findings suggest that markedness/complexity effects have their basis in articulatory constraints. Clearly, this does exclude a role for perceptual constraints. It also does not exclude markedness constraints from having an abstract representation. The opposite, in fact, seems quite plausible. In the history of language evolution, the unmarked syllables are likely to have become those used more widely because they were the easier to produce. Later on, however, constraints on which syllables are allowed by a language may have acquired a more formal representation so that Universal Grammar may offer a choice between levels of syllabic complexy, with any given language setting its own parameter.

It is worth noting that while we have found striking differences in the proportion of simplification errors between our two groups of patient, we have also found similarities in the nature of the errors. Both groups make more deletions in marked than in unmarked contexts and delete the same consonants in the same contexts (e.g., the sonorant consonant in Obstruent-Sonorant onsets; the /s/ in /s/-obstruent-sonorant onsets). Thus, patients with phonological difficulties seem to be as sensitive to syllabic constraints, like patients with articulatory difficulties. The difference is in the proportion of simplification errors made, not in their nature (for details see Galluzzi, Olson & Romani, in preparation). Our results are very similar to those presented by Ouden (2002) for two groups of ten fluent and ten dysfluent patients. He also found more errors reducing marked structures in the dysfluent patients but similar effects of syllabic position in the two groups. Taken together, these results argue for a more central representation of syllabic structure, in addition to the role it plays in determining articulatory complexity (for supporting evidence from dysgraphic patients see Caramazza & Miceli, 1990; Beland, Bois, Seron & Damien, 1999).

Finally, we want to consider the issue of how unitary the concept of syllabic complexity is. In our prediction of accuracy, we have considered together different complex structures based on the principle that each modification of the CV template is a complication. Hierarchies based on this principle have been used widely and profitably in linguistics. Equally, in our analyses of errors, we have considered together complexity in terms of the CV template and complexity in terms of sonority. Again, both these measures have been considered to reflect complexity in the linguistic domain and this has been backed up by distributional data (complex structures occur less often in the world languages; e.g., Greenberg, 1978). Our choice is supported by our results showing strong correlations between simplifications of different syllabic structures as well as between simplifications of CV templates and sonority. These different measures, however, may not always go hand in hand. We have already discussed how AV shows a general tendency to simplify but, at the same time, shows a preference to initiate speech with a single vowel.

It is possible (in fact likely) that, in aphasia, complexity effects will be modulated by the effects that brain damage has on the control of different movements. For example, problems in controlling timing may result in more errors involving sonority changes (i.e., devoicing errors) while problems in controlling the 'energy' of sounds may make easier to start speech with vowels (that are intrinsically of higher energy) than with consonants, as in AV. While it is important that each idiosyncrasy should be explained in the end, this does diminish the importance of the finding that patients with articulatory difficulties find a variety of different types of complex structure hard to produce, that that different measures of complexity pattern together.

## Conclusions

Practical and theoretical reasons may have meant that, to date, complexity effects have been neglected in aphasia. One reason may have been the lack of a clear definition of complexity and the corresponding lack of a clear measure of it. Another reason may have been that it is easier to examine performance in terms of correct/incorrect, than in terms of the type and direction of errors made. However, when performance is analysed in a dichotomous way, complexity needs to be disentangled from phoneme length and syllable length. Finally, research into effects of complexity may have been hindered by a long-standing belief that all aphasic patients make similar kinds of phonological errors (e.g., Canter, Trost & Burns, 1985; Blumstein, 1978).

In the present study we have addressed these problems and demonstrated strong and consistent effects of complexity in some patients but not in others. Our results together with those of other authors (Beland & Paradis, 1997; Beland et al., 1990; Buckingham, 1986, 1990; Christman, 1992; 1994; Romani & Calabrese, 1998; Romani et al, 2002; Ouden, 2002) suggest that complexity effects should be taken into serious consideration both in clinical practice and in constructing models of normal speech production. In clinical practice, effects of complexity should aid with diagnosis of patients' impairments and with monitoring spontaneous recovery and therapeutic success (through more carefully constructed testing materials). Effects of complexity have not been considered by influential models of word production such as those of Dell and collaborators (e.g., Dell,1986; 1988; Dell, Schwartz, Martin, Saffran & Gagnon, 1997; Foygel & Dell, 2000) and Levelt and collaborators (Levelt, 1992; Levelt et al., 1999). They should be. Our results, moreover, suggest that effects of complexity should be placed at the articulatory, and not (or at least not only) at the phonological level. For example, in Levelt's model the syllable units in the syllabary should be organized according to complexity so that simpler syllables are easier to access than more complex syllables.

It is our hope that future studies will recognize: 1) the importance of using a fined grained and comprehensive measure of complexity; 2) the importance of accounting for the totality of the patients' performance (not only whether a response is right or wrong, but also the kinds of errors made); and 3) the importance of testing complexity effects in different patient populations (fluent versus dysfluent; English vs. Italian).

## References

Barcellona Corpus (1988). Instituto di Linguistica Computazionale del CNR di Pisa. Corpus di Italiano Contemporaneo. Unpublished manuscript.

Beland, R., Bois, M., Seron, X., & Damien, B. (1999). Phonological spelling in a DAT patient: the role of the segmentation subsystem in the phoneme-to-grapheme conversion. Cognitive Neuropsychology, 16 (2), 115-155.

Beland, R., Caplan, D. & Nespoulous, J.-L. (1990). The role of abstract phonological representations in word production: Evidence from phonemic paraphasias. Journal of Neurolinguistics, 5 (2/3), 125-164.

Beland, R., & Favreau, Y. (1991). The special status of coronals in aphasia. In C. Paradis and J.F. Prunet (Eds.), The special status of coronals: internal and external evidences. Academic press: San Diego, pp. 201-221.

Beland, R., Paradis, C. (1997). Principled syllabic dissolution in a primary progressive aphasia case: a comparison between paraphasias and loanword adaptations. Aphasiology, 11 (12), 1171-1196.

Berndt, R.S., Haendiges, A.N., Burton, M.W., & Mitchum, C.C. (2002). Grammatical class and imageability in aphasic word production: their effects are independent. Journal of Neurolinguistics, 15 (3-5), 353-371.

Bernhardt, B.H., & Stemberger, J.P. (1998). Handbook of Phonological Development. New York: Academic Press.

Blumstein, S.E. (1978). A phonological investigation of aphasic speech. The Hague: Mouton.

Blumstein, S.E. (1978). Segment structure and the syllable in aphasia. In A. Bell and J.B. Hooper (Eds.), Syllables and Segments (pp 189-200). Holland: North-Holland Publishing Company.

Burani, C., & Cafiero, R. (1991). The role of subsyllabic structure in lexical access to printed words. Psychological Research, 53 (1), 42-52.

Bortolini, V. Tavaglini, C. & Zampolli, A. (1972). Lessico di Frequenza della Lingua Italiana Contemporanea. Milano: Garzanti.

Buckingham, H. W. (1986). The scan-copier mechanisms and the positional level of language production: Evidence from phonemic paraphasia. Cognitive Science, 10, 195-217.

Buckingham, H. W. (1990). Principle of sonority, doublet creation, and the checkoff monitor. In J.-L. Nespoulous and P. Villiard (Eds.), Morphology, Phonology and Aphasia (pp. 193-205). New York: Springer-Verlag.

Buckingham, H.W. (1992). Phonological production deficits in conduction aphasia. In S.E. Kohn (Ed.), Conduction Aphasia, pp 77-116. Hillsdale, N.J.; Lawrence Erlbaum.

Canter, G.J., Trost, J.E., & Burns, M.S. (1985). Contrasting speech patterns in apraxia of speech and phonemic paraphasia. Brain & Language, 24, 204-222.

Caramazza, A., & Miceli, G. (1990). The structure of graphemic representations. Cognition, 37, 243-297.

Caramazza, A., Chialant, D., Capasso, R. & Miceli, G. (2000). Separate processing of consonants and vowels. Nature, 403, 428-430.

Christman, S.S. (1992). Uncovering phonological regularity in neologisms: Contributions of sonority theory. Clinical Linguistics and Phonetics, 6 (3), 219-247.

Christman, S.S. (1994). Target-related neologism formation in jargonaphasia. Brain and Language, 46, 109-128.

Clements, G.N. (1990). The role of the sonority cycle in core syllabification. In J. Kingston and M. Beckmann (Eds.), Papers in Laboratory Phonology 1. Cambridge: Cambridge University Press.

Clements, G.N., & Keyser, S.J. (1983). CV Phonology: A generative theory of the syllable. Cambridge, Ma: The MIT Press.

Colombo, L. (1992). The role of lexical stress in word recognition and pronunciation. Psychological Research, 53, 71-79.

Dell, F. & Elmedlaui, M. (1986). Syllabic consonants and syllabification in Imdlawn Tashlhiyt Berber. Journal of African Languages and Linguistics, 7, 105-130.

Dell, G.S. (1986). A spreading activation theory of retrieval in sentence production. Psychological Review, 93, 283-321.

Dell, G.S. (1988). The retrieval of phonological forms in production: Tests and predictions from a connectionist model. Journal of Memory and Language, 27, 124-142.

Dell, G.S., Juliano, C. & Govindjee, A. (1993). Structure and content in language production: A theory of frame constraints in phonological speech errors. Cognitive Science, 17, 149-195.

Dell, G.S., Schwartz, M., Martin, N., Saffran, E., & Gagnon, D. (1997). Lexical access in aphasic and nonaphasic speakers. Psychological Review, 104 (4), 801-838.

De Renzi, E., Pieczuro, A., & Vignolo, L.A. (1966). Oral apraxia and aphasia, Cortex, 2, p. 250-273.

Duffy, J. (1995). Motor speech disorders: Substrates, differential diagnosis and management. London, Mosby.

Foygel, D. & Dell, G.S. (2000). Models of impaired lexical access in speech production. Journal of Memory and Language, 43, 182-216.

Galluzzi, C., Romani, C. & Olson, A. (in preparation). Syllabic constraints in speech production: evidence from aphasic patients suffering from either phonololgical or articulatory impairments.

Greenberg, J. (1978). Universals of human language, vol 2: Phonology. Standford, Ca: Standford University Press.

Guerssel, M. (1986). Glides in Berber and sillabicity. Linguistic Inquiry, 17, 1-12.

Ingram, D. (1974). Phonological rules in young children. Journal of Child Language, 1, 233-241.

Kaye, J. & Lowenstamm, J. (1981). Syllable structure and markedness theory. In A. Belletti, L. Brandi, and L. Rizzi (Eds.), Theory of markedness in Generative Grammar (pp 287-315). Pisa: Pacini Editore.

Kohn, S.E. (1989). The nature of phonemic string deficit in conduction aphasia. Aphasiology, 3, 209-239.

Kohn, S.E., & Smith, K.L. (1990). Between-word speech errors in conduction aphasia. Cognitive Neuropsychology, 7, 133-156.

Lecours, A.R., & Lhermitte, F. (1969). Phonemic paraphasias: Linguistic structures and tentative hypotheses. Cortex, 5, 193-228.

Levelt, W.J. (1992). Accessing words in speech production: Stages, processes and representations. Cognition, 42, 1-22.

Levelt, W.J., Roelofs, A., & Meyer, A.S. (1999). A theory of lexical access in speech production. Behavioral and Brain Sciences, 22, 1-75.

Lewis, M.B., Gerhand, S. & Ellis, H.D. (2001). Re-evaluating age of acquisition effects: are they simply cumulative-frequency effects? Cognition, 78 (2), 189-205.

Marotta, G. (1988). The italian diphtongs and the autosegmental framework. In P.M. Bertinetto and M. Loporcaro (Eds.), Certamen Phonologicum, papers from Cortona Phonology Meeting. Torino: Rosenberg and Sellier.

Mateer, C., & Kimura, D. (1977). Impairment of nonverbal oral movements in aphasia. Brain and Language, 4, 262-276.

Mckenzie, C. (1982). Aphasic articulatory defect and aphasic phonological defect. British Journal of Disorders of Communication, 17, 27-46.

McNeil, M., Robin, D. & Schmidt, R. (1997). Apraxia of speech:definition, differentiation and treatment. In M. McNeil (ed.) Clinical Management of Sensorimotor Speech Disorders. New York: Thieme, 286-312.

Miceli, G., Laudanna, A., Burani, C. & Capasso, R. (1994). Batteria per l'analisi dei disturbi afasici (B.A.D.A.). Roma: CEPSAG editore.

Miller, D., & Ellis, A.W. (1987). Speech and writing errors in "neologistic jargonaphasia": A lexical activation hypothesis. In M. Coltheart, G. Sartori, & R. Job (Eds.), The cognitive neuropsychology of language. London: Erlbaum.

Nickels, L.A. (2001). Producing spoken words. In B. Rapp (Ed.), A Handbook of Cognitive Neuropsychology. Philadelphia: Psychology Press.

Nickels, L A. & Howard, D. (2004). Dissociating effects of number of phonemes, number of syllables, and syllabic complexity on word production in aphasia: It's the number of phonemes that counts. Cognitive Neuropsychology, 21 (1), 57-78.

Ohala, D. (1999). The influence of sonority on children's cluster reductions. Journal of Communication Disorders, 32, 397-422.

Ouden D.B. Den (2002). Phonology in aphasia: syllables and segments in level-specificdeficits, Groningen dissertations in linguistics. Ipskamp, Enschede: Print Partners.

Paradis, C. & Beland, R. (2002). Syllabic constraints and constraints conflicts in loanword adaptations, aphasic speech and children's errors. In J. Durand & B. Laks (Eds.), Phonetic, Phonology and Cognition. Oxford: Oxford University Press, 191-225.

Prince, A. & Smolensky, P. (1993). Optimality Theory: Constraint interaction in generative grammar. Rutgers University Center for Cognitive Science. Technical Report 2.

Rosenbek, J.C. (2001). Darley and apraxia of speech in adults. Aphasiology, 15 (3), 261-273.

Romani, C. & Calabrese, A. (1998). Syllabic constraints in the phonological errors of an aphasic patient. Brain and Language, 64, 83-121.

Romani, C., Olson, A., Semenza, C. & Grana', A. (2002) Patterns of phonological errors as a function of a phonological versus an articulatory locus of impairment. Cortex, 38, 541-567.

Schwarz, M. F., Saffran, E.M., Block, D.E. & Dell, G.S. (1994). Disordered speech production in aphasic and normal speakers. Brain and Language, 47, 52-88.

Shallice, T., Rumiati, R.I. & Zadini, A. (2000). The selective impairment of the phonological output buffer. Cognitive Neuropsychology, 17, 517-546.

Smith, N.V. (1973). The acquisition of phonology: A case study. Cambridge: Cambridge University Press.

Spencer, A. (1988). A phonological theory of phonological development. In M.J. Ball (Ed.), Theoretical Linguistics and Disordered Language. London and Sydney: Croom Helm.

Steriade, D. (1982). Greek prosodies and the nature of syllabification. Unpublished doctoral dissertation, MIT, Cambridge, Ma.

Stemberger, J.P. (1990). Wordshape errors in language production. Cognition, 35, 123-157.

Stemberger, J.P. (1991). Apparent anti-frequency effects in language production: the addition bias and phonological underspecification. Journal of Memory and Language, 30, 161-185.

Stemberger, J.P., & Treiman, R. (1986). The internal cluster of word-initial consonant clusters. Journal of Memory and Language, 25, 163-180.

## Appendix 1

## Clinical information

| | Age | Sex | **Education** (N of years) | Lesion site | Months post onset |
|---|---|---|---|---|---|
| **Dysfluent** | | | | | |
| DC | 55 | M | 8 | L. temporo-fronto-pariatal | 6 |
| EM | 59 | M | 8 | L. temp-pariatal | 16 |
| AV | 64 | F | 12 | L. fronto-pariatal | 14 |
| DG | 30 | F | 18 | L. temporo-basal, insula, nucleous caudatus and lenticularis, internal capsule | 5 |
| MI | 54 | M | 17 | L temp-pariatal | 24 |
| GC | 55 | M | 12 | Left lenticularis capsule | 24 |
| AP | 60 | M | 8 | Left basal-nucleous | 4 |
| **Fluent** | | | | | |
| MC | 71 | M | 13 | L. pariatal + posterior insula | 6 |
| TC | 32 | F | 13 | Left subaracnoidea perisilviana | 7 |
| MP | 66 | M | 13 | L. temporo-pariatal, cortical subcortical | 4 |
| AC | 71 | F | 13 | L. cisterna silviana | 5 |
| RM | 70 | M | 13 | L. pariatal (basal ganglia + nucleous lenticularis) | 26 |
| GM | 65 | M | 17 | R. pariatal | 2 |

## Appendix 2

## Back-ground neuropsychological tests:

## Task descriptions

Reading involved reading single words presented on a piece of paper. The test consisted of 52 nouns, 20 verbs and 20 function words of various lengths and frequency. Picture naming involved providing the spoken name for a set of black and white drawings depicting common objects. Half of the objects corresponded to high frequency and half to low frequency names matched by length. Spelling to dictation involved 26 nouns, 10 verbs and 10 function words of various lengths and frequency. Single word comprehension required to match a spoken word with one of two pictures. The distracter picture was half of the times semantically related and the other half of the times phonologically related to the target. Results with the phonological distractors will be presented together with the tasks tapping phonological processing. Sentence picture matching involved pointing to one of two pictures in response to a spoken sentence. Half of the sentences were active and half passive. Distractor pictures were of three types. In 1/3 of cases, they were syntactic foils: they corresponded to a sentence which was the reverse of the target (e.g.: target: the dog run after the horse; foil: the horse run after the dog). In 1/3 of cases, they were morphological foils (e.g. target: the girl is chasing the horse; foil: the girl is chasing the horses. In a final 1/3 of cases, they were semantic foils where the picture depicted a noun (or a verb) different but semantically related to the target sentence (e.g.: noun option: target: the boy is eating the ice-cream; foil: the boy is eating the apple; verb option: target: the mother is hugging (holding) the son; foil: the mother is kissing the son).

# Appendix 3

## Back-ground neuropsychological tests.

## Results in % correct.

n.a.= test not administered because the patient was unable to perform the task.

| | | **Word Reading** | **Picture Naming** | **Spelling to Dictation** | **Word-Picture Matching Semantic foils** | **Sentence-picture matching** |
|---|---|---|---|---|---|---|
| | | N=92 | N=30 | N=46 | N=20 | N=60 |
| **Apraxic** | DC | 10.9 | 0.0 | n.a | 90 | n.a |
| | EM | n.a. | 3.3 | n.a | 85 | n.a |
| | DG | 64.1 | 40.0 | n.a | 100 | 100 |
| | MI | 27.2 | 70.0 | n.a | 100 | 78 |
| | GC | 93.5 | 66.7 | 95.7 | 100 | 100 |
| **Slurred** | AV | 46.7 | 36.7 | n.a | 100 | 87 |
| | AP | 85.9 | 53.3 | 93.5 | 100 | 97 |
| **Slow** | MC | 58.7 | 33.3 | 34.8 | 100 | 80 |
| **Fluent** | TC | 76.1 | 56.7 | 76.1 | 100 | 72 |
| | MP | 89.1 | 80.0 | 87.0 | 95 | 92 |
| | AC | 79.3 | 76.7 | 82.6 | 100 | 67 |

## Appendix 4

Different types of errors made by patients in repetition. Word errors: errors which result in a real word of the language; Nonword errors: errors which result in a non existing word. Single phonemes: errors involving no more than three phonemes; Fragments: errors where only a small part of the word is produced (less than 50% of target length); Multiple phonemes: errors changing more than three phonemes; Sequences: errors involving two or more adjacent phonemes.

| | | | | | **Non word errors** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Nonword errors** | | **Word errors** | | Single phonemes | | Fragments | | Multiple phonemes | | Sequences | | Failures to respond | |
| | N | % | N | % | N | % | N | % | N | % | N | % | N | % |
| **Apraxic** | | | | | | | | | | | | | | |
| DC | 654 | 90 | 70 | 10 | 227 | 35 | 1 | 0.2 | 347 | 53 | 78 | 12 | 1 | 0.2 |
| EM | 674 | 96 | 31 | 4 | 443 | 66 | 2 | 0.3 | 172 | 26 | 54 | 8 | 3 | 0.4 |
| DG | 359 | 95 | 17 | 4 | 282 | 79 | 8 | 2.2 | 28 | 8 | 41 | 11 | 0 | 0.0 |
| MI | 302 | 92 | 20 | 6 | 284 | 94 | 1 | 0.3 | 4 | 1 | 13 | 4 | 0 | 0.0 |
| GC | 270 | 95 | 15 | 5 | 258 | 96 | 9 | 3.3 | 2 | 1 | 1 | 0 | 0 | 0.0 |
| **Slurred** | | | | | | | | | | | | | | |
| AV | 373 | 93 | 29 | 7 | 308 | 83 | 2 | 0.5 | 21 | 6 | 42 | 11 | 0 | 0.0 |
| AP | 177 | 94 | 11 | 6 | 153 | 86 | 14 | 7.9 | 2 | 1 | 8 | 5 | 0 | 0.0 |
| **Slow** | | | | | | | | | | | | | | |
| MC | 557 | 93 | 42 | 7 | 375 | 67 | 30 | 5.4 | 130 | 23 | 22 | 4 | 0 | 0.0 |
| **Fluent** | | | | | | | | | | | | | | |
| TC | 153 | 69 | 69 | 31 | 91 | 59 | 36 | 23.5 | 3 | 2 | 23 | 15 | 0 | 0.0 |
| MP | 131 | 65 | 69 | 34 | 88 | 67 | 7 | 5.3 | 21 | 16 | 15 | 11 | 0 | 0.0 |
| AC | 129 | 75 | 49 | 27 | 98 | 76 | 9 | 7.0 | 9 | 7 | 10 | 8 | 3 | 2.3 |
| RM | 129 | 98 | 3 | 2 | 43 | 33 | 80 | 62.0 | 1 | 1 | 3 | 2 | 2 | 1.6 |
| GM | 121 | 94 | 7 | 5 | 99 | 82 | 9 | 7.4 | 4 | 3 | 9 | 7 | 0 | 0.0 |

Table 1: Number of words according to word length (in number of phonemes) and complexity (in number of intra-syllabic clusters) in Lists 1 and 2 used by Nickels & Howard (in press).

| | **Complexity N of clusters** | **Length in number of phonemes** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **2** | **3** | **4** | **5** | **6** | **Total** |
| **List 1** | **0** | | 28 | 30 | 25 | 10 | 93 |
| | **1** | | 1 | 16 | 10 | 18 | 45 |
| | **2** | | - | - | 12 | 0 | 12 |
| | **Total** | | 29 | 46 | 47 | 28 | |
| **List 2** | **0** | 13 | 39 | 4 | 0 | 0 | 56 |
| | **1** | 0 | 5 | 32 | 5 | 0 | 42 |
| | **2** | - | - | - | 1 | 1 | 2 |
| | **Total** | 14 | 44 | 36 | 6 | 1 | |

Table 2. Rate of phonetic errors and speed of utterance for words produced correctly (N=25 for each patient) and incorrectly (N=18 for each patient) by patients and normal speakers. Speed is measured in milsec. Controls = average performance of three normal speakers; Correct words= words repeated correctly; Incorrect words=words containing a single phonological transformation.

| | **PHONETIC ERRORS** | | | **SPEED OF UTTERANCE** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **Correct words** | | | | **Incorrect words** | | | |
| | Patients | | | Patients | Controls | | Diff | Patients | Controls | | Diff |
| | Target | Error | | | | | | | | | |
| **Apraxic** | N | N | % | | Mean | SD | | | Mean | SD | |
| DC | 735 | 102 | **13.9** | 1170 | 544 | 55 | **626** | 1928 | 596 | 67 | **1332** |
| EM | 390 | 59 | **15.1** | 929 | 580 | 71 | **349** | 1182 | 693 | 57 | **489** |
| DG | 773 | 102 | **13.2** | 1230 | 601 | 65 | **629** | 1574 | 697 | 59 | **877** |
| MI | 684 | 164 | **24.0** | 1075 | 584 | 59 | **491** | 1417 | 662 | 57 | **755** |
| GC | 773 | 108 | **14.0** | 1116 | 609 | 63 | **507** | 1753 | 668 | 54 | **1085** |
| **Slurred** | | | | | | | | | | | |
| AV | 574 | 121 | **21.1** | 916 | 612 | 61 | **304** | 1058 | 662 | 55 | **396** |
| AP | 773 | 95 | **12.3** | 719 | 591 | 54 | **128** | 951 | 675 | 90 | **276** |
| **Slow** | | | | | | | | | | | |
| MC | 534 | 22 | **4.1** | 1210 | 609 | 63 | **601** | 1951 | 668 | 79 | **1283** |
| **Fluent** | | | | | | | | | | | |
| TC | 773 | 6 | **0.8** | 782 | 597 | 50 | **185** | 971 | 644 | 58 | **327** |
| MP | 773 | 4 | **0.5** | 692 | 611 | 62 | **81** | 847 | 704 | 54 | **143** |
| AC | 627 | 7 | **1.1** | 766 | 607 | 55 | **159** | 942 | 737 | 77 | **205** |
| RM | 754 | 13 | **1.7** | 734 | 597 | 60 | **137** | 1368 | 746 | 76 | **622** |
| GM | 773 | 14 | **1.8** | 851 | 608 | 58 | **243** | 1094 | 715 | 54 | **379** |

Table 3: Buccofacial apraxia measured as imitations of ten gestures (2 points scored for each completely correct gesture).

| Patients | Bucco-facial apraxia (out of 20 ) | Patients | Bucco-facial apraxia (out of 20 ) |
|---|---|---|---|
| **Apraxic** | | **Slow** | |
| DC | 17 | MC | 20 |
| EM | 16 | **Fluent** | |
| DG | 20 | TC | 20 |
| MI | 12 | MP | 20 |
| GC | 12 | AC | 20 |
| **Slurred** | | RM | 19 |
| AV | 16 | GM | 20 |
| AP | 18 | | |

Table 4: Patient's performance in % correct on tasks assessing phonological input processing. n.a.= not administered; patient unable to perform the task.

| | **Same/different syllables** | **Same/different words** | **Lexical decision** | **Word picture matching Phonol. foils** |
|---|---|---|---|---|
| | N=60 | N=120 | N=80 | N=20 |
| **Apraxic** | | | | |
| DC | 93 | 88 | 89 | 85 |
| EM | n.a. | n.a. | n.a. | 90 |
| DG | 100 | 100 | 100 | 100 |
| MI | 100 | 97 | 95 | 100 |
| GC | 100 | 100 | 100 | 100 |
| **Slurred** | | | | |
| AV | 100 | 96 | 100 | 95 |
| AP | 100 | 100 | 92 | 100 |
| **Slow** | | | | |
| MC | 92 | 96 | 78 | 70 |
| **Fluent** | | | | |
| TC | 100 | 100 | 95 | 95 |
| MP | 92 | 93 | 76 | 90 |
| AC | 87 | 93 | 88 | 90 |
| RM | 100 | 93 | 100 | 100 |
| GM | 100 | 92 | 94 | 100 |

Table 5: Number of words according to word length (in number of phonemes) and complexity score (see text for an explanation) in our corpus.

| **N of Complexities** | **Length in number of phonemes** | | | | | |
|---|---|---|---|---|---|---|
| | **4** | **5-6** | **7-8** | **9-10** | **11-13** | **Total** |
| **0-0.5** | 41 | 73 | 65 | 31 | 2 | 212 |
| **1-1.5** | 17 | 107 | 120 | 64 | 12 | 320 |
| **2-2.5** | 5 | 39 | 81 | 68 | 10 | 203 |
| **3-4.5** | 0 | 0 | 7 | 19 | 12 | 38 |
| **Total** | 63 | 219 | 273 | 182 | 36 | 773 |

Table 6: Effects of different variables (frequency, concreteness, **complexity**, phoneme length and syllable length) in predicting correct repetition in the patients. First all variables have been entered simultaneously to see their relative contribution (only significant values are reported). Secondly complexity has been entered last after frequency, concreteness and phoneme length.

| | Simultaneous regressions | | | | | | | | | | | | Comp. entered last | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Frequency | | Concret. | | **Complexity** | | Phon. Length | | Syll. Length | | Stress | | Complexity | |
| | Wald | p | Wald | p | Wald | p | Wald | p | Wald | p | Wald | p | Wald | p |
| **Apraxic** | | | | | | | | | | | | | | |
| DC | 10.2 | .001 | 5.4 | .02 | | | 36.1 | .000 | | | | | 2.7 | .097 |
| EM | | | | | **30.9** | .000 | | | 22.0 | .000 | | | 17.5 | .00 |
| DG | | | | | **19.0** | .000 | | | 77.4 | .000 | | | 13.3 | .00 |
| MI | | | | | **4.7** | .03 | 19.6 | .000 | | | | | 3.2 | .07 |
| GC | 4.4 | .04 | | | **37.4** | .000 | | | | | | | 13.1 | .00 |
| **Slurred** | | | | | | | | | | | | | | |
| AV | 5.9 | .01 | | | **4.4** | .04 | 11.3 | .001 | | | | | 2.2 | .14 |
| AP | | | | | | | 30.9 | .000 | | | 8.0 | 0.5 | 0.1 | .71 |
| **Slow** | | | | | | | | | | | | | | |
| MC | | | | | | | 25.4 | .000 | | | | | 1.4 | .24 |
| **Fluent** | | | | | | | | | | | | | | |
| TC | 5.5 | 0.2 | | | | | | | 37.0 | .000 | 10.3 | .001 | 0.7 | .40 |
| MP | 7.8 | .005 | | | | | | | | | | | 0.4 | .51 |
| AC | | | 14.6 | .000 | | | 10.3 | .001 | | | | | 1.2 | .28 |
| RM | 7.8 | .005 | | | | | 9.7 | .002 | | | | | 2.5 | .12 |
| GM | | | | | | | | | 30.3 | .000 | | | 0.6 | .44 |

Table 7: Effects of different variables (frequency, concreteness, number of **complex onsets**, phoneme length and syllable length) in predicting correct repetition in the patients. First all variables have been entered simultaneously to see their relative contribution (only significant values are reported). Secondly number of complex onsets has been entered last after frequency, concreteness and phoneme length.

| | Simultaneous regressions | | | | | | | | | | | | Complex onsets entered last | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Frequency | | Concreten. | | **N complex onsets** | | Phoneme Length | | Syllable Length | | Stress | | N complex onsets | |
| | Wald | p | Wald | p | Wald | p | Wald | p | Wald | p | Wald | p | Wald | p |
| **Apraxic** | | | | | | | | | | | | | | |
| DC | 10.2 | .001 | 5.4 | .02 | | | 36.1 | .000 | | | | | 3.3 | .07 |
| EM | | | | | **35.3** | .000 | | | | | | | 2.5 | .11 |
| DG | | | | | **18.2** | .000 | | | 89.5 | .000 | | | 11.5 | .001 |
| MI | | | | | | | 32.3 | .000 | | | | | 0.2 | .90 |
| GC | | | | | **31.8** | .000 | 9.0 | .003 | | | | | 16.8 | .00 |
| **Slurred** | | | | | | | | | | | | | | |
| AV | 5.8 | .02 | | | **19.2** | .000 | 12.6 | .000 | | | | | 16.2 | .00 |
| AP | | | | | **13.0** | .000 | 22.2 | .000 | | | 5.7 | 0.2 | 12.3 | .00 |
| **Slow** | | | | | | | | | | | | | | |
| MC | | | | | | | 25.4 | .000 | | | | | 5.6 | .02 |
| **Fluent** | | | | | | | | | | | | | | |
| TC | 4.6 | .03 | | | **10.3** | .001 | | | 39.7 | .000 | | | 8.3 | .004 |
| MP | 7.8 | .005 | | | | | | | | | | | 0.0 | .86 |
| AC | | | 14.6 | .000 | | | 10.3 | .000 | | | | | 1.4 | .22 |
| RM | 8.1 | .005 | | | **6.0** | .015 | 6.7 | .010 | | | | | 3.4 | .07 |
| GM | | | | | | | | | 30.3 | .000 | | | 1.7 | .19 |

Table 8: Statistics for three lists of words contrasting frequency (high and low), length (short and long) and complexity (simple and complex). Number of stimuli in each categories, standard deviations in parenthesis. Frequencies computed according to the Barcellona Corpus (Barcellona, 1988).

| | **Frequency** | | **Length** | | **Complexity** | |
|---|---|---|---|---|---|---|
| | **HF** | **LF** | **Short** | **Long** | **Simple** | **Complex** |
| **Number** | 95 | 95 | 60 | 60 | 73 | 73 |
| **Phoneme Length** | 5.8<br>(1.5) | 5.8<br>(1.5) | **5.0**<br>(0.8) | **9.0**<br>(0.8) | 7.9<br>(1.5) | 7.9<br>(1.6) |
| **Syllable Length** | 2.5<br>(0.7) | 2.5<br>(0.7) | 2.3<br>(0.5) | 3.9<br>(0.6) | 3.8<br>(0.7) | 3.3<br>(0.8) |
| **Number of complexities** | 1.0<br>(0.6) | 0.9<br>(0.6) | 1.0<br>(0.7) | 1.3<br>(0.8) | **0.2**<br>(0.3) | **2.0**<br>(0.7) |
| **Gram class** | | | | | | |
| Noun | 95 | 95 | 60 | 60 | 33 | 33 |
| Adjective | -- | -- | -- | -- | 40 | 40 |
| **Concreteness** | 1.6<br>(0.6) | 1.7<br>(0.5) | 1.0<br>(0.8) | 0.9<br>(0.8) | 0.5<br>(0.7) | 0.6<br>(0.7) |
| **Frequency** | **360.8**<br>**(319.1)** | **16.8**<br>**(13.9)** | 54.2<br>(40) | 56.9<br>(45.0) | 15.6<br>(20.5) | 17.8<br>(20.4) |

Table 9: Patterns of errors in reading and repetition in patients GC and MC**.**

| | **GC** | | | | **MC** | | | |
|---|---|---|---|---|---|---|---|---|
| | **Reading** | | **Repetition** | | **Reading** | | **Repetition** | |
| | **N** | **%** | **N** | **%** | **N** | **%** | **N** | **%** |
| **Total errors** | | | | | | | | |
| Non-word errors | 320 | **93.3** | 270 | **94.7** | 319 | **86.4** | 557 | **93.0** |
| Word errors | 23 | **6.7** | 15 | **5.3** | 50 | **13.6** | 42 | **7.0** |
| Total | 343 | **44.4** | 285 | **36.9** | 369 | **47.7** | 599 | **77.5** |
| **Non-word errors** | | | | | | | | |
| Single | 293 | **91.6** | 258 | **95.6** | 252 | **79.0** | 376 | **67.4** |
| Multiple | 3 | **0.9** | 2 | **0.7** | 43 | **13.5** | 130 | **23.3** |
| Sequencies | 13 | **4.1** | 1 | **0.4** | 25 | **7.8** | 22 | **3.9** |
| Fragments | 11 | **3.4** | 9 | **3.3** | 33 | **10.3** | 30 | **5.4** |
| **Simpl. – compl. – neutr.** | | | | | | | | |
| Simplifications | 255 | **65.9** | 226 | **68.5** | 72 | **21.1** | 254 | **35.6** |
| Complications | 78 | **20.2** | 45 | **13.6** | 97 | **28.4** | 290 | **40.6** |
| Neutrals | 54 | **14.0** | 59 | **17.9** | 172 | **50.4** | 170 | **23.8** |

Table 10: Number of contextual errors observed and expected within number of total substitution and insertion errors.

| | **SUBSTITUTIONS** | | | | | **INSERTIONS** | | | | | **TOTAL CONTEXTUAL ERRORS** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Anticipations | | Perseverations | | Total errors | Anticipations | | Perseverations | | Total errors | | | |
| | Obs. | Exp | Obs. | Exp. | | Obs. | Exp. | Obs | Exp. | | Obs. | Exp. | Tot sub+Ins |
| **Articulatory** | | | | | | | | | | | | | |
| DC | 18 | 25 | 29 | 14 | 250 | 2 | 1 | 0 | 2 | 25 | 49 | 42 | 275 |
| EM | 85 | 76 | 70 | 42 | 501 | 23 | 16 | 3 | 2 | 84 | 181 | 136 | 585 |
| DG | 35 | 22 | 26 | 30 | 201 | 19 | 10 | 14 | 9 | 65 | 94 | 71 | 266 |
| MI | 22 | 28 | 19 | 21 | 225 | 7 | 5 | 4 | 2 | 27 | 52 | 56 | 252 |
| GC | 28 | 28 | 14 | 14 | 195 | 5 | 2 | 5 | 1 | 13 | 52 | 46 | 208 |
| AV | 53 | 25 | 13 | 9 | 164 | 11 | 6 | 3 | 0 | 23 | 80 | 40 | 187 |
| AP | 18 | 13 | 15 | 9 | 115 | 2 | 1 | 1 | 1 | 7 | 36 | 24 | 122 |
| Total | **259** | 217 | **186** | 140 | **1651** | **69** | 41 | **30** | 17 | 244 | **544** | **415** | 1895 |
| St-dev | 24 | 20 | 20 | 12 | 125 | 8 | 5 | 5 | 2 | 29 | | 37 | 148 |
| **Phonological** | | | | | | | | | | | | | |
| MC | 40 | 37 | 29 | 30 | 402 | 10 | 10 | 5 | 10 | 81 | 84 | 87 | 483 |
| TC | 9 | 10 | 22 | 28 | 99 | 1 | 1 | 3 | 3 | 17 | 35 | 41 | 116 |
| MP | 4 | 15 | 9 | 12 | 85 | 2 | 3 | 0 | 0 | 9 | 15 | 30 | 94 |
| AC | 3 | 8 | 8 | 9 | 83 | 2 | 4 | 1 | 1 | 12 | 14 | 22 | 95 |
| RM | 14 | 5 | 10 | 11 | 74 | 7 | 2 | 3 | 3 | 20 | 34 | 29 | 100 |
| GM | 15 | 10 | 19 | 18 | 95 | 0 | 0 | 2 | 1 | 5 | 36 | 21 | 94 |
| Total | **85** | 85 | **97** | 108 | **838** | **22** | 20 | **14** | **18** | **144** | **218** | **230** | **982** |
| St-dev | 14 | 10 | 9 | 9 | 129 | 4 | 4 | 2 | 4 | 28 | 25 | 25 | 157 |

Table 11. Number and proportions (out of instances in the corpus) of simplifications of different syllabic structures by patient.

| | Complex onset elimination | | Coda elimination | | Single vowels elimination | | Hiatuses elimination | | Geminates into singletons | | Clusters into geminates * | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | % | N | % | N | % | N | % | N | % | N | % |
| **Apraxic** | | | | | | | | | | | | |
| DC | 45 | **14** | 19 | **5** | 4 | **9** | 5 | **9** | 6 | **2** | 48 | **13** |
| EM | 102 | **32** | 57 | **15** | 64 | **44** | 0 | **0** | 14 | **6** | 62 | **16** |
| DG | 39 | **12** | 10 | **3** | 2 | **1** | 17 | **30** | 6 | **2** | 23 | **6** |
| MI | 59 | **19** | 8 | **2** | 0 | **0** | 4 | **7** | 3 | **1** | 5 | **1** |
| GC | 53 | **17** | 2 | **1** | 0 | **0** | 6 | **11** | 0 | **0** | 46 | **12** |
| **Slurred** | | | | | | | | | | | | |
| AV | 94 | **30** | 7 | **2** | 8 | **5** | 9 | **16** | 3 | **1** | 25 | **7** |
| AP | 29 | **9** | 4 | **1** | 1 | **1** | 3 | **5** | 1 | **0** | 3 | **1** |
| **Slow** | | | | | | | | | | | | |
| MC | 49 | **15** | 10 | **3** | 5 | **3** | 4 | **7** | 9 | **4** | 23 | **6** |
| **Fluent** | | | | | | | | | | | | |
| TC | 9 | **3** | 1 | **0** | 0 | **0** | 3 | **5** | 6 | **2** | 1 | **0** |
| MP | 12 | **4** | 2 | **1** | 0 | **0** | 2 | **4** | 0 | **0** | 1 | **0** |
| AC | 16 | **5** | 3 | **1** | 1 | **1** | 0 | **0** | 2 | **1** | 2 | **1** |
| RM | 11 | **3** | 1 | **0** | 1 | **1** | 0 | **0** | 0 | **0** | 1 | **0** |
| GM | 7 | **2** | 0 | **0** | 0 | **0** | 2 | **4** | 1 | **0** | 7 | **2** |

* Clusters into geminates: this refers to inter-syllabic clusters; e.g., asta>atta

Table 11: Pattern of correlations between simplifications of different types of complex syllabic structures (in terms of CV templates).

| Simplifications of: | **Complex onsets** | **Codas** | **Single vowels** | **Hiatuses** | **Geminates** | **Clusters** |
|---|---|---|---|---|---|---|
| **Complex onsets** | 1 | **.70** ** | **.67*** | .24 | **.57*** | **.73*** |
| **Codas** | | 1 | **.98**** | -.11 | **.84**** | **.75**** |
| **Single vowels** | | | 1 | -.21 | **.78**** | **.71**** |
| **Hiatuses** | | | | 1 | .06 | .19 |
| **Geminates** | | | | | 1 | **.61*** |
| **Inter-syllabic clusters** | | | | | | 1 |

** Correlations is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

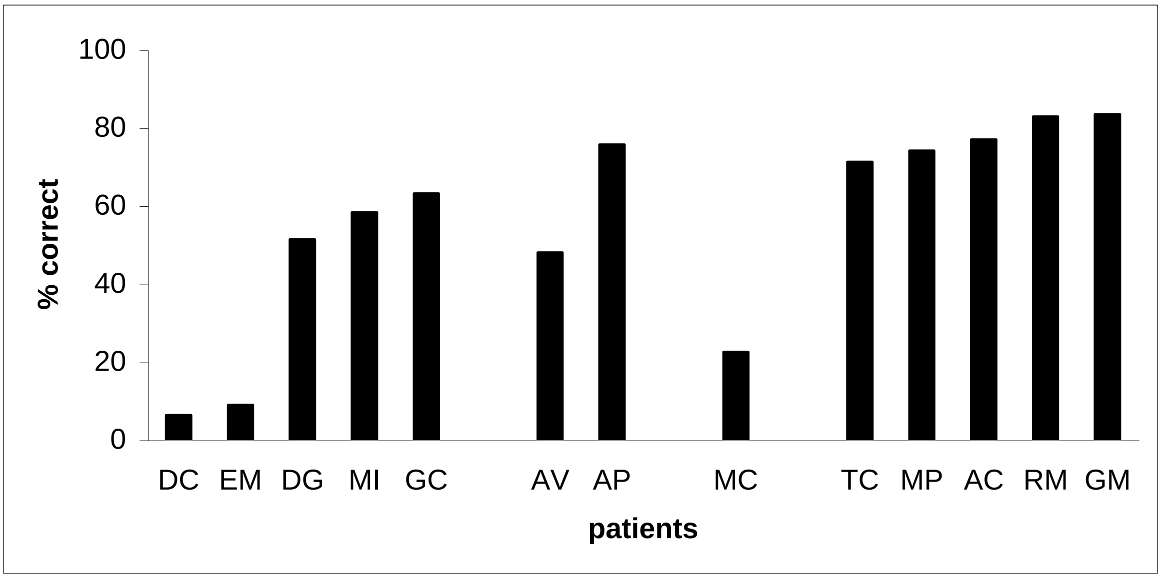

figura 1: Proportion of correct responses in repeating 773 words by different patients

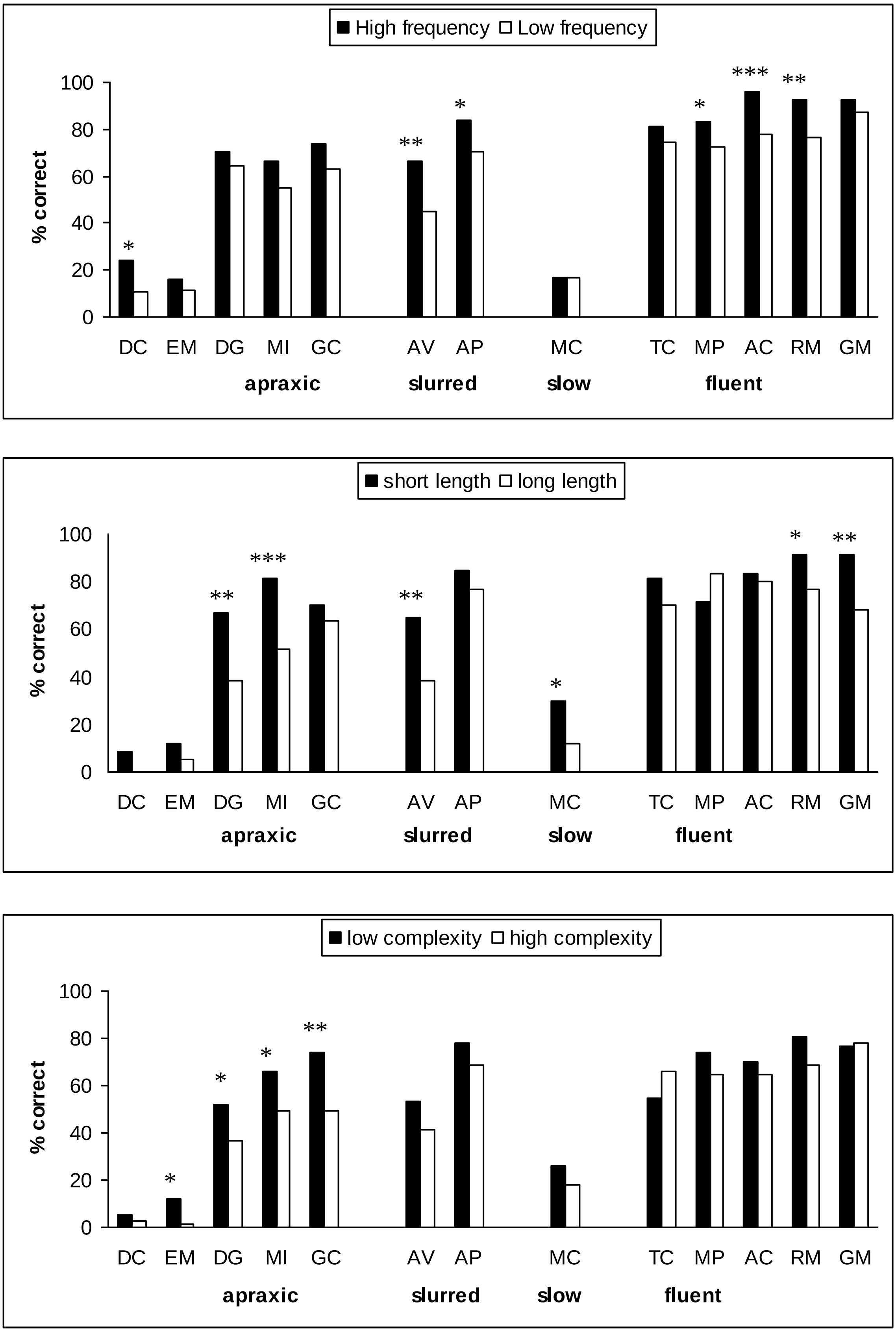

Figure 2: Proportion correct responses in lists assessing effects of frequency, length, and complexity by different patients. * = p<.09; ** = p<.01; *** = p<.001.

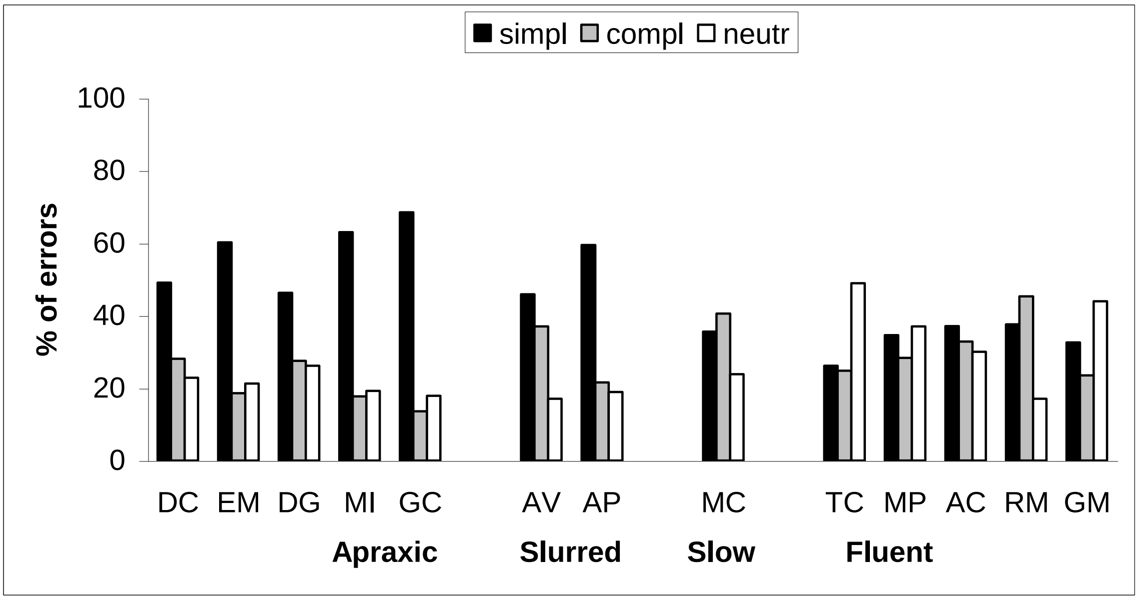

Figure 3: Proportion of errors resulting in syllabic simplifications, complications or no change from the target word for different patients.

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