

Note

## A dedicated neural mechanism for vowel selection: A case of relative vowel deficit sparing the number lexicon

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Received 29 November 2005; received in revised form 27 June 2006; accepted 8 July 2006

Available online 25 September 2006

### Abstract

We report the case of an Italian speaker (GBC), with classical Wernicke's aphasia following a vascular lesion in the posterior middle temporal region. GBC exhibited a selective deficit in spoken language production affecting vowels more than consonants. In reading from a newspaper, GBC substituted vowels for other vowels from the Italian inventory at a rate of 7/1 compared to consonants. No effects of frequency or grammatical class were found. Vowel errors could also not be accounted for by morphological or known phonological processes. Production of number words, in contrast, was free from phonological errors. While GBC has intact representations of Italian vowels and consonants, his data argue for a separate selection mechanism for vowels that is dissociable from that used for consonants. This case provides neuropsychological evidence for models of word production that distinguish between the abstract phonological properties of a word (e.g., sequencing of phonemic slots, or "CV skeleton") and a separate representation for the specific sounds (melody).

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**Keywords:** Vowels; Consonants; Aphasia; Vowel production; Number words

A pervasive finding in the literature on phonological errors in speech is that on average, aphasics and normal speakers make more errors on consonants than on vowels (Béland, Caplan, & Nespoulous, 1990; Blumstein, 2001; Canter, Trost, & Burns, 1985; see Dressler, Tonelli, & Magno Caldognetto, 1990, for Italian). The incidence of selective deficits on vowels in aphasia is unknown, but, like many selective deficits, we can expect it to be low, and therefore, virtually undetectable in group studies where individual differences between the patients are often lost.

The general aphasiological literature (reviews can be found in Blumstein, 2001; Denes, Semenza, & Magno Caldognetto, 1999; Nickels, 2001) has focused on broad phonological differences between classic aphasic syndromes, and relatively little attention has been devoted to the phonemic level. Studies that

have dealt with the neural basis of phoneme production generally assume a neural network distributed in perisylvian areas.

Based on patterns of phonological errors in aphasics, a model proposed by Blumstein (2001) distinguishes between a lexical selection and a phonological planning stage before articulatory implementation. On this model, patients with conduction aphasia would have difficulty in the planning stage, while those with Wernicke's aphasia would struggle at the lexical selection stage. Conduction aphasics frequently approximate the sound structure of the target word: their phonemic substitutions seldom differ from the target in more than one distinctive feature. It is believed that they correctly select the lexical target but fail in properly realizing the phonetic details of the word. In contrast, the production of Wernicke's aphasics often does not closely resemble the phonological structure of the target, suggesting that the problem lies in selecting the correct target word among competing lexical candidates. However, as is the case with most phonological studies in aphasia, this model is based on data from

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consonant substitutions and does not deal in any detail with the production of vowels.

There are only two published studies on patients exhibiting selectively impaired performance on vowels compared to consonants: case MM (Romani, Granà, & Semenza, 1996), and case AS (Caramazza, Chialant, Capasso, & Miceli, 2000). These studies were conducted in repetition. Both patients were native Italian speakers with left-temporo-parietal vascular lesions resulting in typical conduction aphasia. The case studies with MM and AS do not address whether their deficit is one of vowel representation or vowel selection. They also fail to examine the respective contribution of articulatory, prosodic, and lexical factors on error patterns.

The present investigation reports a third case of relative vowel deficit, with some important additional findings. It provides a more in-depth investigation of the nature of the errors, revealing an intact abstract representation for the phonological skeleton of a word (CV skeleton), and a deficit in selecting the specific vowel from an equally intact language specific vowel inventory. Additionally, this patient produced number words without phonemic deficits. Dissociations resulting in intact phonological performance on number words in the face of impaired phonology on other word classes have been reported before (e.g., Cohen, Verstichel, & Dehaene, 1997). We will argue that the number lexicon may be accessed by a separate non-semantic route in which number words are retrieved as sequences of preassembled, phonetically spelled-out, units.

## 1. Case report

At the beginning of this investigation, GBC was a 62-year-old, still active and successful business man, with only 5 years of formal education. He had a long history of vascular problems. In 1996, he suffered and immediately recovered from a transitory ischemic episode with language problems affecting the production side. In February 1998, he suffered an ischemic lesion in the left posterior temporal area, resulting in fluent aphasia of the classical Wernicke type. An old ischemic lesion in the left

occipital lobe was also found on that occasion. In May 1998, he underwent a bypass between the superficial temporal artery and the middle cerebral artery. The procedure was complicated a few days after the intervention by bleeding in the temporo-parietal area.

In December 2004, GBC was evaluated at the Neurology Department of the Istituto Auxologico Italiano of Verbania, where the present investigation took place from January to May 2005. An MRI taken in April 2005 revealed a vascular lesion in the posterior middle temporal region (Fig. 1). Aphasia was the only detectable neurological impairment.

GBC's full neuropsychological evaluation also revealed significant symptoms for aphasia only. His language functions were evaluated via a battery of tests including the Italian version of the Aachen Aphasia Test (Luzzatti, Willmes, & De Blaser, 1996), and portions of the Miceli, Laudanna, and Burani (1994) battery for the assessment of aphasia in Italian. GBC's Wernicke's aphasia was stable during the investigation and was distinguished by well-articulated, relatively fluent, paraphasic and paragrammatic speech, severely affected repetition and naming, and moderately impaired auditory comprehension. In each production task, it became obvious that the majority of single phoneme errors affected vowels rather than consonants. This unusual observation led to the present investigation.

GBC's native language was Italian, in the Piemontese variant spoken by communities in the west side of Lago Maggiore (Province of Verbania). He competently spoke standard Northern Italian with the experimenters, with a regional Piemontese accent. GBC collaborated enthusiastically throughout the investigation.

## 2. Experimental investigation

### 2.1. Collection of spoken material

GBC was tape-recorded in all experimental tasks. Three judges, all native speakers of GBC's dialect independently transcribed the tapes. GBC's articulation was very clear. No more than a couple of words were coded as unintelligible, and these were due to voice lowering. Inter-judge agreement was close to 100%.

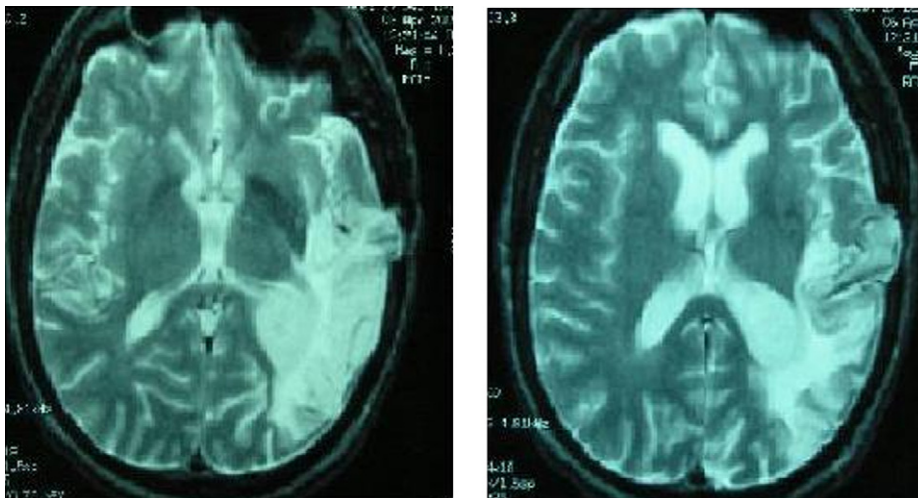


Fig. 1. MRI showing posterior middle temporal lesion in case GBC.

## 2.2. Background testing

This section reports in detail a number of tests to determine the best task to examine the vowel relative to consonant deficit. Unless otherwise stated, these tasks were taken from the Miceli et al. battery (1994). All tasks used an even number of high and low frequency targets where applicable.

### 2.2.1. Picture naming

In picture naming of objects and actions (half low and half high frequency items), GBC made 40/58 errors, again mostly consisting of non-target-recognizable neologisms; the few phoneme substitutions concerned vowels only.

### 2.2.2. Repetition

In repetition of single words (15 nouns, 15 verbs, and 15 function words, all three/four syllables long), GBC made 32/45 errors, mostly neologisms with little to no relation to the target: only five single phoneme substitutions were found, four of which concerned vowels.

### 2.2.3. Phonemic discrimination and spoken-to-written syllable matching

Phonemic discrimination and spoken-to-written syllable matching tasks were administered to determine whether GBC's repetition errors were due to a phonological comprehension problem. Both tasks contrasted pairs of CV syllables, presented one at a time. (Consonants were occlusives, e.g., PA, TA, CA, BA, DA, GA; answer yes/no). GBC showed a mild deficit; he made 7/60 errors on the phonemic discrimination task, and 6/60 errors when matching spoken-to-written syllables.

### 2.2.4. Lexical decision ("is this a real word or not?")

In the auditory modality, GBC made 13/40 errors on real words (10 nouns, 10 adjectives, 10 verbs, and 10 function words), and 1/40 errors on non-words. In the visual modality, he only made 2/40 errors on real words and 4/40 on non-words.

### 2.2.5. Lexical discrimination

To assess the receptive aspect of reading, GBC was given 40 pairs of written words, 4–10 letters long: 20 pairs were the same word written in a different font ("casa" – house – "CASA"), the other 20 pairs consisted of words differing by one letter only; either a consonant or a vowel ("RAMO" – branch – "remo" – oak). He was flawless in deciding whether the two words were the same or different.

### 2.2.6. Reading aloud

In single word reading (52 nouns, 20 verbs, 20 function words—words were half high and half low frequency), GBC made 10/92 errors, 8 of which were vowel substitutions. He was less efficient in connected prose, where the rate of phonological errors was similar to that found in spontaneous speech (where he produced some neologisms but more semantic paraphasias and anomia hesitations). No between-word errors were observed.

### 2.2.7. Word class and length effects: reading and repetition of numbers

While there was an overall word length effect, no clear frequency, concreteness, or grammatical category effects appeared. The category of numbers however, was an exception. GBC not only had a digit span of four but also correctly repeated all complex numbers up to three digits (comprehension problems hampering his performance only with longer numbers). He could read (in Arabic and alphabetic codes) complex numbers up to eight digits ( $N$  of items: 50) without being affected by phonemic errors. His errors were limited to lexical substitutions (e.g., thirty-six → forty-two); virtually no number "syntax" violation was detected.

A test was built in which GBC was administered 75 words embedding a number word. For example: "lotto" – lotto – embeds "otto" – eight, "alisei" – tradewinds, embeds "sei" – six. GBC substituted vowels in 16/75 words, four substitutions occurred on the embedded number words. The same number words were also embedded in 75 non-words derived from the previous corpus by changing one or two phonemes from the non-number part of the words. GBC made 20/75 vowel substitutions, four of which were on the embedded number

words. This shows that, for GBC, if a number word was contained in a larger unit (whether this was a real word or not) it was not processed as a number word, and therefore it was not immune from vowel errors.

## 2.3. Interim discussion

Little is known about complex number reading, but one possibility is that large numbers are parsed into smaller sequences of more frequent basic number words (e.g., four, thousand, five, hundred, etc.) (Cohen et al., 1997).

Basic number words in Italian (number words for digits 1–19, tens, hundreds, thousands, million(s) and the suffix – mila, – thousand) are one to four syllables in length and vary in stress pattern (e.g., "trè" – three, "ùno" – one, "ùndici" – eleven). They contain 94 vowels and 110 consonants (vowel rate 85%). The distribution of vowels within the basic Italian number lexicon is comparable to the distribution of vowels within the general Italian lexicon. The frequencies of vowels /a/, /e/, /i/, /o/, /u/, in the basic number lexicon are as follows: (cf. frequency in the entire lexicon in parenthesis): /a/ 20 (25), /e/ 20 (28), /i/ 34 (20), /o/ 16 (20), /u/ 10 (7).

Number words have a restricted number of possible intra-category competitors and, indeed, GBC's only errors were "lexical" substitutions; he made virtually no number "syntax" violations. His lexical errors consisted of substituting the whole lexical unit with another lexical unit, and could not be accounted for by contextual vowel substitutions.

Even if complex numbers are read by parsing them into smaller more frequent units, GBC's performance cannot be explained on a frequency factor: as mentioned above, and shown also in reading connected speech, he made vowel errors even on extremely high frequency function words, such as prepositions and articles.

Therefore, the preservation of number words in this patient does not appear to stem from particular lexical or phonological properties of number words (such as frequency or distribution of phonemes), rather it stems from the possibility of accessing number words via non-semantic routines (see Section 3).

## 2.4. Reading connected prose

The first series of tasks showed that GBC made phonemic errors predominantly on vowels in all oral production tasks besides spontaneous speech. Due to his Wernicke's aphasia, GBC made semantic errors both in repetition and picture naming, resulting in neologisms that are difficult to interpret. His reading aloud was relatively free from other errors. Therefore, we chose a reading rather than a spoken task to investigate his unusual error pattern. GBC made more errors in reading connected prose than single words. Because he was comfortable with reading prose, despite the greater difficulty of the task, the investigation of GBC's phonological errors was therefore conducted by having him read a newspaper article aloud, as this allowed us to collect a more sizeable corpus of errors.

The choice of a reading task is particularly appropriate for Italian, because the relationship between phonology and orthography in this language is "one-to-one" and transparent to a large degree.

GBC spoke Standard Northern Italian, a system with five vocalic phonemes /a/ /e/ /i/ /o/ /u/ (Mioni, 2001). Unlike English and many other languages, vowels in Italian are always full. There are no phonological reduction processes that result in the production of the neutralized central vowel "schwa". This may explain why selective substitution errors on vowels have not been noticed in the aphasiological literature, which has focused predominantly on English.

## 2.5. Comparing vowels and consonants

GBC's newspaper article was written in standard Italian and consisted of 2882 words (with an average of 2.8 syllables), with 15,042 letters (with 6963 vowels and 8079 consonants). He made 632 word errors (errors were counted only in cases where the target word was still identifiable); 436 of the errors were single phoneme errors. These errors were distributed over 410 words because sometimes multiple phonemic errors occurred in the same word (e.g., "sfortunatamente\*" instead of "sfortunatamente"). Of the errors, 69/436 were deletions ("pitre\*" instead of "pietre") and 49/436 were insertions (e.g., "ni" within "ultrinifondamentalista\*", instead of "ultrafondamentalista"). Single

Table 1  
Confusion matrix for single phoneme errors in full and restricted error sample (in bold)

	a	b	tʃ	k	d	e/ε	f	dʒ	g	ʎ	η	i	l	m	n	o/ɔ	p	r	s	z	ʃ	t	u	v	ts	dz	Total
a	<b>75</b>					<b>65</b>						<b>24</b>				<b>79</b>							<b>4</b>			<b>172</b>	
b		<b>3</b>															<b>3</b>									<b>3</b>	
tʃ			<b>1</b>																							<b>1</b>	
k				<b>2</b>																						<b>2</b>	
d					<b>1</b>								<b>7</b>													<b>8</b>	
e/ε	<b>33</b>					<b>19</b>						<b>16</b>										<b>1</b>				<b>69</b>	
f	<b>7</b>					<b>6</b>						<b>4</b>										<b>0</b>				<b>17</b>	
dʒ			<b>1</b>																							<b>1</b>	
g				<b>3</b>																						<b>3</b>	
ʎ													<b>2</b>													<b>2</b>	
η																										<b>0</b>	
i	<b>12</b>					<b>50</b>						<b>15</b>										<b>6</b>				<b>83</b>	
l	<b>5</b>					<b>11</b>						<b>2</b>										<b>1</b>				<b>19</b>	
m																										<b>0</b>	
n				<b>1</b>								<b>3</b>	<b>4</b>					<b>1</b>	<b>1</b>							<b>10</b>	
o/ɔ	<b>27</b>					<b>15</b>						<b>10</b>										<b>2</b>				<b>54</b>	
p	<b>10</b>					<b>5</b>						<b>1</b>										<b>2</b>				<b>18</b>	
r																										<b>0</b>	
s				<b>1</b>	<b>2</b>																						<b>2</b>
z													<b>1</b>														<b>2</b>
ʃ																											<b>0</b>
t					<b>1</b>																						<b>1</b>
u	<b>3</b>					<b>4</b>						<b>1</b>															<b>18</b>
v	<b>0</b>					<b>1</b>						<b>0</b>															<b>6</b>
ts							<b>1</b>						<b>1</b>														<b>2</b>
dz																											<b>0</b>
<b>Total</b>	<b>75</b>	<b>0</b>	<b>1</b>	<b>5</b>	<b>3</b>	<b>134</b>	<b>1</b>	<b>1</b>	<b>2</b>	<b>0</b>	<b>0</b>	<b>54</b>	<b>6</b>	<b>6</b>	<b>0</b>	<b>120</b>	<b>3</b>	<b>1</b>	<b>3</b>	<b>0</b>	<b>0</b>	<b>8</b>	<b>13</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>436</b>
	<b>22</b>	<b>0</b>	<b>1</b>	<b>5</b>	<b>3</b>	<b>30</b>	<b>1</b>	<b>1</b>	<b>2</b>	<b>0</b>	<b>0</b>	<b>13</b>	<b>6</b>	<b>6</b>	<b>0</b>	<b>42</b>	<b>3</b>	<b>1</b>	<b>3</b>	<b>0</b>	<b>0</b>	<b>8</b>	<b>6</b>	<b>0</b>	<b>0</b>	<b>153</b>	

phoneme errors were the more frequent informative type of error and thus underwent further analysis.

## 2.6. Analysis of phonological errors in restricted sample

We examined only those errors that could safely be attributed to phonological factors: morphological (“potrà” – (s)he will be able to – instead of “potrò” – I will be able to) (“diretto” – direct, instead of “diritto” – law), and semantic (“donare” – donate, instead of “denaro” – money) errors were excluded from further analysis. The restricted sample contained 111 non-words (\*) substituting one (in most cases) or more phonemes in response to given target words (“islīmīca\*” instead of islamica – Islamic; “ferīci\*” instead of “feroci” – ferocious; “sembra\*” instead of “sembra” – it seems). There were 407 vowels, 113 of which were substitutions. Table 1 shows the confusion matrix both for the full sample of 410 words and for the restricted sample of 111 words.

## 2.7. Vowels

Substitutions were made for /a/ in 48.1%, /e/ in 22.0%, /i/ in 19.0%, /o/ in 17.8%, and /u/ in 31.7% of their respective occurrences. The direction of

substitutions was the following:

- /a/ became /e/ in 24.5% of substitutions, /i/ in 11.3%, /o/ in 58.5%, and /u/ in 5.7%;
- /e/ became /a/ in 41.2%, /i/ in 35.3%, /o/ in 23.5%, and /u/ in 0.0%;
- /i/ became /a/ in 26.3%, /e/ in 57.9%, /o/ in 10.5%, and /u/ in 5.3%;
- /o/ became /a/ in 55.5%, /e/ in 27.8%, /i/ in 5.6%, and /u/ in 11.2%;
- /u/ became /a/ in 0.0%, /e/ in 16.7%, /i/ in 0.0%, and /o/ in 83.3%.

The relative frequency of vowels in spoken Italian (Tonelli, Panzeri, & Fabbro, 1998) is the following: /a/: 25.3%, /e/: 28.1%, /i/: 20.1%, /o/: 20.0%, and /u/: 6.5%. Thus, GBC’s errors were determined by neither a frequency criterion, nor by substituting another vowel at chance.

We examined whether errors were affected by phonological assimilatory processes, such as vowel harmony. Vowel harmony does not occur in Standard Italian, but it does in many of the dialects (e.g., Rohlf, 1966). The most common type of harmony (aka, metaphony) is height harmony, where a high post-tonic vowel triggers the raising of a stressed mid vowel. We considered whether cases where the mid vowels /e/ and /o/ were realized as /i/ and /u/ could be due to the presence of a high vowel in any post-tonic position. Substitutions due to



metaphony were extremely rare; there were only six errors where tonic /e/ was replaced by /i/, and of those only three matched the context for metaphony (e.g., “dicibel” instead of “decibel”). In only two cases was /o/ raised to /u/, and neither had the right context for metaphony. The patient’s performance could not be attributed to vowel harmony.

It was conceivable that vowel substitutions were influenced by word stress (for this analysis, monosyllabic words were excluded). Only 10.2% of errors on vowels were located on stressed vowels. Furthermore, Italian orthographic conventions explicitly mark accented vowels in final position (e.g., “università”—*university*). GBC made only one error on an explicitly accented vowel. It appears that in fact, word stress protected vowels from substitution.

We also looked at the role of phonological distance in substitution. As an approximate distance measure, we considered proximity in vowel space along the backness and height dimensions. Of GBC’s errors, 97/113 (86%) were substitutions between vowels that were contiguous either on the front/back dimension (/e/ replaced with /i/) or the height dimension (e.g., /e/ replaced with /o/), and resulted in a vowel that was proximal to the target vowel. GBC’s vowel substitutions appeared to be influenced to some degree by contiguity in phonological vowel space.

### 2.8. Consonants

There were very few consonant substitutions, thus the meaning of any computation on GBC’s production of consonants is of limited value. However, modelling Caramazza et al. (2000), correlations were calculated between the sonority scale for Italian consonants, the percentage of errors for each target consonant segment, and the percentage of consonant types produced as an error: both correlations were non-significant. Notably, sonorous consonants (i.e., /l/ and /r/) were not affected any more than other consonants. Another analysis compared the error rates for consonants that are distinguished by dorsal features (high, back, and low) with those for other consonants. As in Caramazza et al. (2000), no significant difference was found.

### 3. General discussion

GBC’s relative vowel deficit manifests itself in production and is considerably larger than deficits found in previously studied cases. GBC produced almost seven times as many substitution errors on vowels than on consonants (the vowel/consonant error rate was approximately 3/1 in Caramazza et al., 2000, and 2/1 in Romani et al., 1996).

GBC’s articulation is flawless, suggesting that the deficit is not located in the peripheral aspects of production, such as the motoric implementation of the articulatory gestures. Crucially, because GBC makes very few errors on consonants and substitutes vowels with other vowels from the Italian inventory, his performance suggests intact phonological representation of an abstract category vowel (V) as well as intact articulatory gestures for Italian vowels. GBC’s problem is neither one of representation nor articulatory implementation, rather one of selection of a vowel to “spell out” the phonological slot with the appropriate vowel quality, or melody.

GBC’s performance is best captured in models of phonological access that assume the existence of an abstract phonological frame with place holders for sequences of consonants and vowels (e.g., Dell, 1988). To account for the selectivity of GBC’s deficit, we propose a representation borrowed from multi-linear theoretical models of phonology, along the lines of McCarthy (1981). In this model, an abstract phonological frame (or CV skeleton) is linked to separate tiers that specify, or spell out, the content of individual consonants and vowels. Fig. 2 shows the phonological representation for the word “gatto”—*cat*.

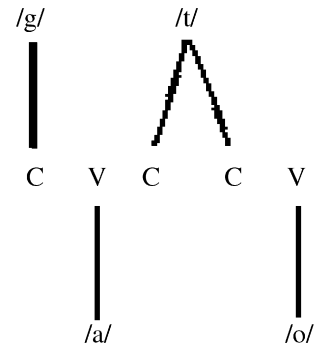


Fig. 2. Phonological representation of the Italian word *gatto* (cat). Note that separate levels represent vocalic and consonantal slots (the CV skeleton), which are then filled with separate phonemic specifications for vowels and consonants, selected from a language specific inventory.

GBC’s error free production of number words in contrast, suggests that the output phonetic forms of number words in this patient are retrieved as (sequences of) full basic number words with segmental information already phonetically spelled out. That is, without necessarily generating a phonetic code from lexical (semantic) and more abstract phonological representations. Unlike the production of other words in the lexicon, number words can be produced via dedicated numeral (orthographic or Arabic)-to-spoken name transcoding algorithms that need not contain semantic information (Cipolotti & Butterworth, 1995), and may be modality specific (Campbell, 1995). This suggests that all patients with phonological deficits at the word activation level would be relatively less impaired when producing number words than other word categories. Indeed, this appears to be the case. Cohen et al. (1997) describe a case of phonological jargon where the patient made phonemic errors on all words except for number words.

In summary, this study provides evidence for a neurologically based dissociation in the production of vowels and consonants. Along with previous cases, it suggests that separate brain systems underlie the representation of abstract phonological information such as the number and sequencing of vowel and consonant positions (CV skeleton) and the selection mechanisms that “spell out” the C and V slots. The selection mechanism for vowels is separable from the selection mechanism for consonants, as it can be selectively impaired. More research is needed to determine what factors influence the selection mechanism, but for GBC, vowel selection did not appear to be influenced by phonological context. Word stress assignment protected vowels from errors. Further investigations of cases such as GBC should allow us to specify the neurological underpinnings of this complex production system.

### Acknowledgments

This research was supported in part by a grant from the Italian Ministry of Education and from a Marie Curie Network Grant (NUMBRA) to the first author. Thanks to GBC for his enthusiastic collaboration.

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