2017-09-15

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Romani, C

http://hdl.handle.net/10026.1/10814

10.1080/02643294.2017.1369942
Cognitive Neuropsychology
Informa UK Limited

COGNITIVE NEUROPSYCHOLOGY, 2017
https://doi.org/10.1080/02643294.2017.1369942

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Comparing phoneme frequency, age of acquisition, and loss in aphasia: Implications for phonological universals

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ABSTRACT
Phonological complexity may be central to the nature of human language. It may shape the distribution of phonemes and phoneme sequences within languages, but also determine age of acquisition and susceptibility to loss in aphasia. We evaluated this claim using frequency statistics derived from a corpus of phonologically transcribed Italian words (phonitalia, available at phonitalia,org), rankings of phoneme age of acquisition (AoA) and rate of phoneme errors in patients with apraxia of speech (AoS) as an indication of articulatory complexity. These measures were related to cross-linguistically derived markedness rankings. We found strong correspondences. AoA, however, was predicted by both apraxic errors and frequency, suggesting independent contributions of these variables. Our results support the reality of universal principles of complexity. In addition they suggest that these complexity principles have articulatory underpinnings since they modulate the production of patients with AoS, but not the production of patients with more central phonological difficulties.

ARTICLE HISTORY
Received 26 April 2017
Revised 31 July 2017
Accepted 3 August 2017

KEYWORDS
Aphasic errors; featural markedness; phoneme acquisition; phoneme frequencies

1. Introduction

Not all phonemes are born equal. Some seem to have a privileged status: They occur more frequently across different languages and are more frequent within languages (Greenberg, 1978; Ladefoged & Maddieson, 1996; Maddieson, 1984), are acquired earlier by children (e.g., Kager, Pater, & Zonneveld, 2004; Stoel-Gammon, 1985), and are better preserved after brain damage (see Jakobson, 1941/1968 for the original hypothesis; see Buchwald, 2009; Galluzzi, Bureca, Guariglia, & Romani, 2015; Marquardt, Reinhart, & Peterson, 1979; Romani & Galluzzi, 2005; Wolk, 1986, for empirical evidence). These observations suggest the existence of hierarchies of phonological complexity, which are universal and hold across different domains of investigation because they are grounded in characteristics of the human articulatory or perceptual apparatus. The existence of such hierarchies is central to many linguistic theories and to theories of language development as outlined below. In spite of this, however, we have very little empirical evidence of the consistency of measures derived from different domains whereas this will help us to better specify the nature of complexity principles and the extent of their influence. The purpose of this study is to provide this evidence by assessing the association between measures of phoneme frequency that have recently become available for Italian (phonItalia.org; Goslin, Galluzzi, & Romani, 2014), measures of phoneme resilience in aphasia (from error corpora recently described in Galluzzi et al., 2015), and measures of phoneme age of acquisition (AoA; derived by Zanobini, Viterbori, & Saraceno, 2012).

We should note from the start that we assess associations between production measures: how often phonemes are *produced* in the adult language, how early they are *produced* by children, and how well they are *produced* by aphasic patients. We do not consider perceptual measures. It is likely that perceptual and production measure complexity will correlate because phoneme distributions will be affected by both how easy it is for a phoneme to be produced and how easy it is to be perceived. However, assessing the relative impact of production and perceptual measures of complexity across domains is beyond the scope of this paper.

The role of within-language frequency in explaining linguistic regularities has been increasingly

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recognized, although, for the most part, the debate has focused upon lexical, morphological, and syntactic representations rather than phonological representations per se (see Barlow & Kemmer, 2000; Bod, Hay, & Jannedy, 2003; Bybee & Hooper, 2001; Diessel, 2007). For example, it has been noted that, if there is a discrepancy in the number of morphemes used to represent singular and plural words, then the singular words, which are used more frequently, are represented with fewer morphemes. This makes them shorter and less effortful to produce (accordingly, nouns that are used most commonly in the plural form are often not marked by an extra morpheme; see, in English, people, fish, etc.). The same principles should hold in the phonological domain. Phonemes and phonological sequences that are simpler should be used most often. For example, Piantadosi, Tily, and Gibson (2012) have provided a nice demonstration of the tendency of language to use and re-use easier phonological forms by showing that words that are shorter, are more frequent, and use sequences with higher phonotactic probability are associated with higher degrees of homophony and polysemy. It remains to be determined, however, what simplicity/complexity refers to, how strong these complexity effects are across different domains, and how complexity effects are modulated by other variables. Before tackling these issues, we now briefly outline how complexity principles have come to the forefront of linguistic theories.

1.1. Complexity in linguistic theories

Linguists have long noted that certain speech sounds occur more often than others and tried to explain these differences by referring to their relative complexity. The Russian linguist Roman Jakobson first proposed the notion of implicational universals, according to which, if a language has a structure at a given level of complexity, it also has the simpler structures. It follows that while all languages have the simplest structures, progressively fewer languages will have the more complex structures, depending on the level of complexity that they decide to tolerate. Moreover, in his famous book *Child Language, Aphasia and Phonological Universals,* Jakobson (1941/1968) argued that implicational universals operate in the same way in language acquisition and in aphasia. In acquisition, a more complex structure implies the acquisition of the simpler counterpart. In aphasia, more complex structures are lost before simpler ones. This is known as the "regression hypothesis".

In the sixties, Greenberg, following the ideas of Jakobson and, more generally, of the Prague school of phonology, published a short book outlining what he believed to be universal principles that dictate which language structures are intrinsically simpler than others across phonology, morphology, and semantics (Greenberg, 1966–2005, *Language Universals: With Special Reference to Feature Hierarchies*). These principles were derived chiefly from phonology. In phonology, the "unmarked" values of phonemes will be those that require a position of the articulators closer to their position at rest, and which, therefore, require less effort to be produced than the secondary "marked" version.[1] Unmarked values will be identified by a number of characteristics: (a) They will be those preserved when a contrast is neutralized in a given linguistic environment (the marked feature will change to unmarked); (b) they will show more allophonic variability and characterize the basic allophone[2]; (c) they will characterize more phonemes than the corresponding marked values (or an equal number, never fewer phonemes); crucially (d) they will be more frequent in the language than the corresponding marked values. Note that the fourth characteristic is a direct consequence of the first three.

In the era of *generative phonology* (Chomsky & Halle, 1968, *The Sound Pattern of English*), principles of complexity took a less central role in linguistic theories. The emphasis was on how to derive *surface* phonological representations from deeper, more primitive representations using a formalized set of rules. Markedness principles influenced the application of these rules only in a limited way (although see Stampe, 1973, who stressed universal complexity principles based on articulation, and also Kiparsky & Menn, 1977; Kisseberth, 1970, and Menn, 1980, who put forward the idea of different rules "conspiring" towards the same goal of avoiding certain complex structures). *Principles and Parameters* (Chomsky, 1997) introduced the idea of a universal grammar as a set of parameters with binary values that can be set "on" or "off". Complexity principles were more important here since the default settings of the grammar were assumed to be the unmarked/simpler values of phonemic features. During language acquisition, some parameters are set to marked values on the basis of input from the environment. Different languages switch on different parameters. *Principles and Parameters* paved the way for the most popular current approach—optimality theory—where principles of complexity play a central role since they determine the phonemic inventory of a language.

In *optimality theory* (OT; Kager et al., 2004; Prince & Smolensky, 1993, 2004), universal grammar is seen as a set of *markedness constraints*. Which structures are allowed by a language is determined by the interaction between markedness constraints (MARK)—which limit the inventory of a language by allowing only the simplest structures—and faithfulness constraints (FAITH)—which expand the inventory of a language by promoting faithfulness to the structures used by the community of speakers. MARK are not fulfilled in a deterministic way, but in different ways that depend on the interaction with FAITH. For example, a prohibition against a type of complex onset (e.g., /bn/) may be fulfilled by deletion of a consonant (bn/>/b/), substitution of a consonant (e.g., /bn/>/pn/), or epenthesis of a vowel (/bn/>/ben/). These transformations will all reduce the complexity of the onset, but which one is used will depend on the strength of faithfulness constraints, which prevent deletion of a syllabic position, modification of phonological features, or inclusion of extraneous material. During acquisition, the child's output is initially totally unmarked since all structural constraints dominate faithfulness constraints. With development, MARK are progressively demoted compared to FAITH to allow the emergence of progressively more complex structures. Individual grammars arise from a different ranking of markedness and faithfulness constraints. Some languages have complex structures because the corresponding faithfulness constraints end up being ranked above markedness constraints. Others do not have them because the corresponding markedness constraints retain a high ranking.

Finally, more recent approaches have stressed phonetic *grounding of phonology*, with a blurring of the traditional distinction between a phonological and a phonetic level of explanation. According to these approaches, phonological representations, rules, and constraints are all emergent properties of stochastic learning principles and anatomo-physiological properties of the acoustic and articulatory apparatus. Thus, these approaches strongly emphasize the phonetic underpinnings of constraints, which act on a speech output simultaneously and directly rather than through sets of formally ordered rules (see Archangeli & Pulleyblank, 1994; Blevins, 2003; Hayes, Kirchner, & Steriade, 2004).

1.2. Complexity across domains: Possible outcomes and implications

While principles of complexity have been central to linguistic theories, linguistic complexity hierarchies have been derived mainly on the basis of cross-linguistic distributions, and the basis of complexity principles remains hotly debated. While most linguists working in the OT framework assume that markedness is grounded in phonetic/articulatory complexity (for this position and a discussion see Bermúdez-Otero & Börjars, 2006; de Lacy, 2006; Kingston, 2007; Ohala, 1997), others believe that markedness is an abstract formal principle independent of physical properties (e.g., Hale & Reiss, 2000). Finally, while some have assumed markedness to be grounded in articulatory complexity (e.g., Browman & Goldstein, 1992), others have privileged perceptual complexity (e.g., Kingston, 2007). Evidence of the association between hierarchies derived from language frequency, AoA, and aphasic speech may be very useful both to reach a better understanding of what complexity is and to gauge its relative contribution to phoneme production across domains. Different empirical scenarios are possible with different implications.

A *strong correspondence across domains will be consistent with a single underlying factor affecting phoneme distributions in speech.* In and of itself, however, this correspondence will not elucidate the nature of this underlying factor. According to one view, *frequency* in the language could be the main factor driving the association. Phonemes that are more frequent will provide children more opportunities to practise, will end up with a stronger representation in the brain, and will be more resilient to brain damage. Recent approaches have stressed the impact of experience and statistical regularities in shaping language (see; Bybee & Hooper, 2001; Graf Estes & Bowen, 2013; Graf Estes, Edwards, & Saffran, 2011; Jusczyk, Luce, & Charles-Luce, 1994; MacKenzie, Curtin, & Graham, 2012). These approaches stress practice over complexity as driving ease of production.

Alternatively, the association between phoneme acquisition rate, distribution within and between languages, and aphasic errors may be mediated by *complexity* principles either abstract or grounded in the characteristics of the human perceptual/articulatory apparatus. According to this view, the same phonemes are frequent within and between languages, are produced earlier by children, and are preserved in aphasia because these are *the phonemes that humans find easier to produce*. These complexity principles could be formalized in a set of innate ranking constraints as in classic OT (e.g., see Browman & Goldstein, 1992; Prince & Smolesky, 2004) or act more directly in shaping production through articulatory constraints (see Blevins, 2003; Pierrehumbert, 2001a, 2001b, for approaches stressing phonetic-based learning). This last hypothesis is consistent with radical views that see language acquisition occurring without recourse to any innate linguistic principles and "universal grammar" as only a myth. Even for these views, however, it would be important to establish whether common complexity principles drive language production across domains, even if these principles are based on physical rather than abstract linguistic properties (see Evans & Levinson, 2009; Everett, 2016, but also extensive, ensuing commentary to Evans & Levinson, 2009, for alternative views endorsing the reality of a universal language faculty). From now on, we refer to these complexity principles as markedness constraints. It is one of our empirical questions whether they are abstract or have articulatory underpinnings.

Two considerations are important in considering the nature of markedness constraints. The first one relates to whether markedness constraints, which have largely been derived from *cross-linguistic* hierarchies, correspond to *within*-language frequency. A good correspondence between markedness and frequency will support the existence of universal principles with *wide* influences on speech production. On the other hand, a lack of correspondence will limit the role of markedness. It would suggest that, although markedness may affect which phonemes are present or not in a language, it will have limited influence on *their frequency* because vocabularies drift in different directions on the basis of idiosyncratic language histories.

Another consideration is whether correspondences are found between markedness rankings and the distributions of errors made by *all* aphasic patients or only with the errors made by patients with articulatory difficulties. If the errors of all types of aphasic patients are associated with markedness constraints (as well as with frequency and AoA), this would suggest that practice and/or abstract markedness are driving the associations. Instead, if associations are found *only or mainly* with the *apraxic patients* who present independent evidence of articulatory difficulties, this would support the hypothesis that phonetically grounded markedness principles are driving the associations. If markedness principles are not grounded in articulation there is no reason to expect that only the apraxic patients will be sensitive to the difficulty hierarchies shown in acquisition and language frequency.

Of course, frequency and markedness could both affect language production and interact with each other. If this is the case, we should be able to uncover some distinct effects. For example, if markedness and frequency are independent factors (and markedness is based on articulation), phoneme AoA and errors in apraxia of speech (AoS) should be related to markedness and to each other because articulatory proficiency is a limiting factor for both children and aphasic patients. Instead, frequency may relate less to markedness because articulatory complexity is less of a limiting factor in adults with a fully developed articulatory capacity. Crucially, however, the variables more strongly associated to one another may be markedness and AoS errors on one side and frequency and AoA on the other. This is because, although both children and aphasic patients will be affected by articulatory complexity, practice (indexed by frequency) will be more relevant to children than to adults, who have a lifetime of exposure to their community's language.

1.3. Predictions

In summary, there is a surprising lack of empirical evidence for the regression hypothesis in phonology, although Jakobson's (1941/1968) original formulation was in this domain. More generally, there is little empirical evidence concerning the nature of phonological complexity effects. Our study contributes to the debate on the relative importance of practice/frequency of input versus innate complexity principles in language production. We assess how phonological markedness—a theoretical concept, loosely motivated by cross-linguistic phoneme distributions—is related to *empirical measures* in three domains: (a) corpus linguistics with measures of phoneme frequency in the language, (b) language development, with measures of phoneme age of acquisition, and (c) neuropsychology, with measures of phoneme articulatory difficulty in patients with apraxia of speech. Measures of phoneme frequency are derived from the corpus PhonItalia, which has phonologically transcribed the COLFIS corpus of Italian words (see Goslin et al., 2014). Measures of age of phoneme acquisition are derived from a published report (Zanobini et al., 2012). Measures of phoneme articulatory difficulty are derived from corpora of errors made by aphasic patients with AoS tested in our laboratory. Associations with rate of errors from patients with AoS are contrasted with associations with rate of errors in patients with more central phonological deficits.

Our results address three main hypotheses, which are outlined in Table 1, together with the predictions that follow. To anticipate our results, predictions which correspond to our obtained results are highlighted in the table.

1. *Speech production is driven only by frequency of input.* Linguistic markedness has no psychological reality and does not make any meaningful contribution to speech production. It is either a reflection of frequency or a linguistic concept whose validity is limited to explaining cross-linguistic distributions. This hypothesis predicts a strong association between language frequency and both AoA and AoS, but *limited or no associations* between markedness rankings and empirical measures of frequency, AoA, AoS.
2. *Speech production is driven only by principles of linguistic markedness.* Frequency is only a reflection of markedness. This hypothesis predicts *strong association* between markedness and empirical measures of phoneme frequency, AoA, AoS.
3. *BOTH frequency AND markedness contribute independently to explain speech production.* This hypothesis predicts *strong associations* between markedness and all empirical measures: phoneme frequency, AoA, and difficulty of articulation (AoS errors). It also predicts some asymmetries in associations: (a) Markedness may relate more to AoA and AoS errors than to frequency; (b) phoneme acquisition may sometimes be driven by frequency and other times by markedness; (c) frequency and markedness may make independent contributions to AoA and AoS errors; AoA may relate more strongly to frequency and AoS errors relate more strongly to markedness.

3A. *Phonological markedness is an abstract principle.* This hypohtesis also predicts that all errors should be affected whether they arise from phonological or apraxic difficulties.

3B. *Phonological markedness is rooted in articulation.* This hypothesis also predicts that markedness should explain distribution of errors in patients with AoS, but not distributions of errors in patients with more central phonological difficulties.

1.4. Plan of study

To assess our hypotheses, we run four main kinds of analyses. First, we assess correlations between our three main empirical variables: phoneme frequency, phoneme AoA ranks, and phoneme error rates in aphasic individuals with AoS (from now on AoS errors). All our hypotheses predict associations. Finding associations demonstrate that our measures are sensitive and work well for our purposes. Second, we assess in a qualitative way patterns of correspondences between markedness rankings—for manner, place, and voicing contrasts—and the rankings provided by our empirical variables. If markedness is a significant factor affecting speech production, we expect significant associations between markedness rankings and language frequency as well as with AoA and AoS errors. However, if markedness and frequency *both* contribute independently to phoneme acquisition we may also expect that the acquisition of some phonemes will depend more on frequency while the acquisition of others will depend more on markedness. Third, we carry out some statistical regression analyses to assess the relative contribution of our variables to predict AoA and AoS errors. If markedness and frequency are independent variables they should make independent contributions to explain AoA and AoS errors. Finally, we contrast associations in patients with AoS and more central phonological difficulties. If markedness is an abstract phonological principle, there should be no difference in the degree of association shown by the errors of patients with AoS or more

Table 1. Hypotheses and predictions.

		Predictions					
		Associations between empirical variables	Association markedness/frequency	Asymmetries in markedness/ frequency association for different linguistic contrasts	Asymmetries in degree of association	Asymmetries regression analyses	Difference between aphasic groups
Hypotheses Production is driven by		Frequency is associated with AoA and AoS errors; AoA and AoS are also associated to one another	Markedness is associated with frequency (as well as with AoA and AoS)	Acquisition of some phoneme is best predicted by markedness, of other phonemes by frequency	AoA more related to Frequency; AoS more related to markedness	Frequency. and Markedness make independent contributions to AoA and AoS	Contrast between individuals with AoS vs. Phonological difficulties
1. One factor only: FREQUENCY of input	*1A. Markedness is only a reflection of frequency*	Yes	Yes	No: frequency always predicts best	No: frequency always predicts best	No	No: frequency predicts all errors
	1B. Markedness makes no contribution	Yes	No			No, only frequency predicts	
2. One factor only: innate MARKEDNESS–*frequency is a reflection of markedness*	*2A. Markedness is an abstract principle*	Yes	Yes	No: markedness always predicts best	No: markedness always predicts best	No, no independent contributions	No:
	2B. Markedness is phonetic and rooted in articulation	Yes	Yes				Yes: Markedness only predicts AoS errors
3. Two factors: Innate MARKEDNESS + FREQUENCY	*3A. Markedness is an abstract principle*	Yes	Yes	Yes	Yes	Yes	No
	3B. Markedness is phonetic and rooted in articulation	Yes	Yes	Yes	Yes	Yes	Yes: Markedness only predicts AoS errors

Note: "Yes" indicates that the prediction in the heading is made by the relative hypothesis; "no" indicates otherwise. The shaded areas indicate predictions that are fulfilled by the results. AoA = age of acquisition; AoS = apraxia of speech.

central phonological difficulties. Instead, if markedness is based on articulatory difficulty, it should only predict the errors of patients with AoS.

2. Overall method

2.1. Language frequency measures

Frequency statistics for Italian single consonants will be derived from *phonItalia*, a corpus of phonologically represented Italian words derived from the Colfis corpus of written words (Bertinetto et al., 2005). *PhonItalia* has 120,000 word entries associated with type and token frequency. From these we have derived type and token frequencies for individual phonemes (overall and distinguished by syllabic position) and for consonantal clusters (full database available at phonItalia.org; see also Goslin et al., 2014, for a full description). There are pros and cons in using raw or log frequency for our analyses. Phoneme frequencies are almost linearly distributed with a very modest exponential component. This is in contrast to word frequency where there is a clear over-representation of words in the very-high-frequency band (Baayen, 1992). Phonemes are a very restricted set compared to the hundreds of thousands of words present in a language lexicon, and high-frequency phonemes are much in line with a linear distribution of frequencies. In our initial table, we present results in terms of both raw and log frequencies; after that we use log frequencies, but it should be understood that results with other types of frequency measures are very similar.

2.2. Age of acquisition measures

Only a few studies have provided detailed results on the AoA of Italian consonants (e.g., Bortolini, 1995; Zanobini et al., 2012; Zmarich & Bonifacio, 2005). In our investigation, we rely mainly on the studies of Zanobini et al. (2012) and Zmarich and Bonifacio (2005), which provide the most detailed results. Given the relevance of these studies to our analyses we describe their methodology in some detail. In both studies, AoA is measured by considering the words produced by children at a given age. It is assumed that which words are included in a child's lexicon and produced correctly is determined by the phonological/articulatory complexity of their constituent phonemes.

Zmarich and Bonifacio (2005) used a methodology similar to that of the seminal study by Stoel-Gammon (1985). They recorded the speech produced by 13 children during play interactions with their mothers at four different time points: when they were 18, 21, 24, and 27 months old. During each session, the child was asked to manipulate, name, and talk about a small set of toys. The authors were interested in the phonemes present in the early "words" used by children. "Words" are considered forms with a stable association to meaning, regardless of whether the form corresponds to the adult target. Only children with vocabulary >10 words were included in the study. Following Stoel-Gammon (1985), a phoneme was considered attested in an individual child if it was present in at least two different words produced during the playing session. A phoneme was considered attested across the group if it was produced by at least 7/13 children and consolidated if produced by at least 12/13 children.

The study by Zanobini et al. (2012) examined the synchronic spoken production of a group of 30 older children between the ages of 36 and 42 months (with ages overlapping with the study by Bortolini, 1995). Materials from Bortolini (1995) were used to elicit spontaneous speech. Each child was asked to tell three stories illustrated by sets of pictures (two stories with six pictures and one story with four pictures). Consonant acquisition was measured in terms of the number of children who produced that consonant correctly in initial word position, medial word position, or both. We have combined measures in initial and final position to derive a combined measure that distinguishes *different ranks of phoneme acquisition* as follows:

Rank 1: present in at least 90% of children in *both* initial and medial position;
Rank 2: present in at least 90% of children in *either* initial or medial position;
Rank 3: present in at least 70% of children in *either* initial or medial position and in at least 10% of children in the other position;
Rank 4: present in at least 70% of children in either initial or medial position;
Rank 5: present in at least 10% of children in either initial and medial position;
Rank 6: present in none of the children in either position.

While these measures tell us that a phoneme was produced correctly by the child during the testing session, they do not give any indication of how many times the phoneme was attempted and produced incorrectly. Still these measures provide a reasonable approximation of consonant acquisition in Italian children that may be compared to adult frequency and aphasic speech.

2.3. Articulatory difficulty/aphasic measures

In a series of previous papers, we have analysed the phonological errors made by aphasic individuals across production tasks (single word repetition, reading, and picture naming) according to whether or not they result in phonological simplifications of syllables (through deletions and insertion errors) or simplifications of individual phonemes (through substitutions). Simplifications have been defined using cross-linguistic-based complexity hierarchies. We have found simplifications to characterize the speech of aphasics with independent evidence of articulatory difficulty (individuals with apraxia of speech, AoS), but not the speech of aphasics without associated difficulties (phonological aphasics; see Galluzzi et al., 2015; Romani & Galluzzi, 2005; Romani, Galluzzi, Bureca, & Olson, 2011; Romani, Galluzzi, & Olson, 2011; Romani, Olson, Semenza, & Granà, 2002). Please note that both groups of our aphasic participants make what are perceived as phonological errors. However, it is only in the group with associated phonetic errors (therefore classified as having AoS) that these errors result in simplifications suggesting that they are motivated by articulatory difficulties (also see Laganaro, 2012; Ziegler, Aichert, & Staiger, 2012, for views of AoS as a disorder in articulatory planning, at the interface between phonology and articulation, and Buchwald & Miozzo, 2011, for another example where error analyses in aphasia are used to identify level of impairment).

In the present study, we report frequency and AoA measures for different linguistic categories together with the error rate of 11 individuals with AoS. In an overall summary table at the end of our experimental investigation, we also report overall results for 10 aphasics with phonological production impairments (classifiable as conduction aphasics).

All our aphasic participants (apraxic and phonological) have been selected for making a large number of phonological errors in speech production tasks (including spontaneous speech), for an absence of peripheral dysarthric difficulties (e.g., systematically distorted speech), and for relatively good phonological discrimination abilities. All participants suffered from a left-hemisphere stroke except one who suffered a right CVA (cerebrovascular accident) and one who suffered a close head injury. They all had a confirmed diagnosis of aphasia. They have been subdivided into apraxic and phonological groups on the basis of rates of phonetic errors in word repetition (>10% and <5%, respectively). Speech errors have been collected using three production tasks involving repetition and reading of single words and picture naming (number of words for repetition and reading, $N = 773$; for picture naming, $N = 236$–412). Some general information for individual patients is presented in the Appendix. Since these patients have been extensively described in previous publications, we refer the reader to them for more details (see Galluzzi et al., 2015; Romani, Galluzzi, Bureca, & Olson, 2011).

In the rest of the paper, results are presented as average error rates on individual phonemes out of total stimuli in the corpus: number of incorrect phonemes out of total number of target phonemes. Results are averaged across individual participants, tasks, and type of errors. Since we present results in terms of error rate, we can only consider substitutions and deletions (with insertions there is no target). Although results had some individual variability, patterns were quite homogeneous within groups.

2.4. Brief description of Italian phonology

A full description of Italian phonology is beyond the scope of the present paper. Here we present just enough information to make our analyses understandable and refer the reader to other work for more complete descriptions (e.g., Kramer, 2009; Rogers & d'Arcangeli, 1999). Italian has 22 consonants (for a listing and examples see Table 2; Zanobini et al., 2012). They can be divided into two main classes according to manner of articulation: obstruents and sonorants.

Obstruents are produced with a complete or semicomplete obstruction in the air flow. Italian obstruents include: six *plosives or stops* (p, t, k, b, d, g); four

Table 2. Measures of phoneme frequency, phoneme acquisition, and phoneme articulatory difficulties.

Symbol			Phoneme language frequency				Phoneme child acquisition			Phoneme articulation	
			TokenFreq.		TypeFreq.		N produced		AoA	Aos errors	
IPA	PhonItalia	Example	Raw	Log	Raw	Log	W Initial	W Medial	Rank	*N*	%
n	**n**	**n**ave [ship]	1,193,267	**6.08**	69,115	**4.84**	27	3	2	314	**3.7**
t	**t**	**t**ana[den]	1,151,501	**6.06**	83,848	**4.92**	27	30	1	253	**2.2**
r	**r**	**r**ana [frog]	1,082,468	**6.03**	81,414	**4.91**	12	28	3	991	**9.3**
l	**l**	**l**ana [wool]	898,432	**5.95**	42,387	**4.63**	30	30	1	452	**6.6**
s/z	**s**	**s**ale [salt]	857,307	**5.93**	55,371	**4.74**	29	16	2	382	**5.8**
k	**k**	**k**ane [dog]	637,446	**5.8**	39,278	**4.59**	30	27	1	335	**5.6**
d	**d**	**d**ito[finger]	594,549	**5.77**	25,764	**4.41**	26	22	3	473	**16.4**
p	**p**	**p**ino [pine]	485,715	**5.69**	27,948	**4.45**	30	23	2	206	**4.5**
m	**m**	**m**ano [hand]	446,039	**5.65**	30,659	**4.49**	30	15	2	155	**3.6**
v	**v**	**v**oce [voice]	294,196	**5.47**	19,240	**4.28**	28	22	3	417	**18.3**
j	**j**	**j**eri [yesterday]	249,734	**5.4**	16,525	**4.22**	0	27	4	185	**7.0**
f	**f**	**f**ame [hunger]	187,581	**5.27**	14,200	**4.15**	25	0	4	251	**8.5**
ts	**z**	ti**tstsi**o[guy]	175,804	**5.25**	12,184	**4.09**	0	0	6	136	**8.4**
b	**b**	**b**acio [kiss]	165,864	**5.22**	14,666	**4.17**	25	5	3	329	**15.8**
ʧ	**c**	**ʧ**ena [dinner]	165,300	**5.22**	13,398	**4.13**	16	21	3	140	**7.3**
w	**w**	**w**ovo [egg]	130,437	**5.12**	5134	**3.71**	0	27	4	61	**5.9**
ʤ	**g**	**ʤ**oco [game]	121,624	**5.09**	10,070	**4.00**	7	0	5	180	**18.9**
g	**G**	**g**atto [cat]	95,160	**4.98**	9728	**3.99**	4	0	5	489	**29.5**
ʎ	**L**	a**ʎʎ**o [garlic]	76,278	**4.88**	4055	**3.61**	0	1	5	47	**7.4**
ɲ	**N**	**ɲ**omo [gnome]	49,064	**4.69**	3365	**3.53**	0	5	5	58	**23.8**
ʃ	**S**	**ʃ**okko [stupid]	45,706	**4.66**	3759	**3.58**	0	4	5	29	**13.9**
dz	**Z**	**dz**ukka [pumpkin]	25,640	**4.41**	3944	**3.60**	0	0	6	36	**17.4**

Note: AoA = age of acquisition; AoS = apraxia of speech; TokenFreq. = token frequency; TypeFreq. = type frequency N produced = number produced; W initial = word initial; W medial = word medial. Phoneme frequency from PhonItalia. Phoneme acquisition includes AoA rank. Articulatory difficulties: % of errors in patients with AoS. Italian consonants are ordered by token frequency. Acquisition data here and in all the tables are from Zanobini et al. (2012). They show number of children aged 36–42 months (out of 30) who have acquired consonants in initial or medial word position. Ranks are based on averages across positions (see text). Percentages of aphasic errors are out of stimuli in the corpus.

fricatives (f, v, s, ʃ), and four *affricates* (ʧ, ʤ, ts, dz). Plosives and affricates are produced with a complete constriction of the air flow followed by a release burst, while fricatives are produced with a more limited closure, which does not stop the air flow, but makes it turbulent. Affricates are complex consonants where a complete closure is followed by turbulence. Within each class, consonants contrast for voicing (for stops: unvoiced /p/, /t/, /k/ vs. voiced /b/, /d/, /g/ ; for fricative: unvoiced /f/ vs. voiced /v/; for affricate: unvoiced /ʧ/ vs. voiced /ʤ/) and place of articulation (for stops: *labial,* /p/, /b/, vs. *dental/alveoar,* /t/, /d/, vs. *velar,* /k/, /g/; for fricatives: *labial*, /f/, /v/, *alveolar,* /s/ and *post-alveolar*, /ʃ/; for affricates: *alveolar,* /ts/, dz/ vs. *post-alveolar*, /ʧ/, /ʤ/). A main characteristic of Italian stops compared to their English equivalents is a lack of aspiration.

Sonorants are produced with a continuous air flow. Italian sonorants include three *nasals* (m, n, ɲ), three *liquids* (l, r, ʎ), and two *glides* (j, w). They are all voiced. Liquids and nasals differ because the velum is lowered in nasal but not in liquid consonants. Glides are produced with a very open vocal tract akin to vowels. Within each class, sonorants contrast for *place* of articulation (for nasals: *labial,* /m/, *alveolar,* /n /, *palatal,* /ɲ/; for liquids: *alveolar*, /l/, /r / vs. *palatal,* /ʎ/; for glides: palatal, /j/ vs. labial, /w/). Liquids also differ in terms of whether air stream is forced to the side of the mouth (lateral consonants /l/ and /ʎ/) or is repeatedly interrupted as in a rhotic or trill (/r/). The Italian /r/ is an apical consonant, produced with the tip of the tongue vibrating against the alveolar region. It is usually realized as a tap—a single brief interruption of the air flow—when short and as a trill with more vibration when geminated [e.g., birra (beer) vs. mare (sea); see Kramer, 2009; Rogers & d'Arcangeli, 1999]. Rhotic sounds, such as the Italian /r/, are difficult to produce because vibrations are not created by independent movements, but by the airflow passing through a small gap between the speech organs. The size of the gap and the strength of the air flow must be just right for the vibration to occur.

All Italian consonants, but glides, can geminate with contrasting effects. However, /ɲ/, /ʎ/, /ts/, /dz/ are always geminated in intervocalic position. Also note that here we are describing Italian phonology; some phonemes have allophonic variants depending on context; a notable example is /s/ produced as /z/ in intervocalic position.

2.4.1. Voicing

Italian, like many other languages, and all the European languages, contrast stop consonants with binary +/– voiced feature (but there are languages with more varied contrasts, up to six, according to Kager, Van der Feest, Fikkert, Kerkhoff, & Zamuner, 2007). A main acoustic parameter associated with voicing is the voice onset time or VOT. This refers to the interval between release of the articulatory closure producing the consonant and the start of vibration of the vocal folds. In all languages, *voiced segments start vibration earlier* compared to unvoiced segments. However, different languages use different VOT intervals for categorization, and other parameters such as aspiration and articulatory force contribute to the distinction. In so-called *voice-led languages*, like Italian, Dutch, French, and Spanish, unvoiced consonants are realized by starting vibration of the vocal cords soon after release of the closure, while voiced consonants are realized by starting vibration actually *before* release of closure (voice-led). In Italian, the VOT for voiced plosive is between −125 and −75 ms (values from Bortolini, Zmarich, Fior, & Bonifacio, 1995), while VOT for voiceless plosive is between 0 and 25 ms. This contrasts with so-called *aspiration languages*, like English and German, where unvoiced stops (especially if in onset position) are aspirated. In these languages, voiced stops are generally realized with a short lag similar to that used for voiceless consonants by other languages (but also sometimes with voice-led), while unvoiced stops have a much longer VOT, coinciding with the length of the aspiration. In English, for example, the VOT of voiced consonants is generally between 0 and 25 ms, for unvoiced consonants between 35 and 80 ms (values from Blumstein, Cooper, Goodglass, Statlender, & Gottlieb, 1980). The added complication pf aspiration may produce different complexity ranking, as discussed later.

3. Experimental results

3.1. Frequency, AoA, and AoS—all consonants

Our first analysis considers associations between our empirical measures: frequency, AoA, and AoS errors. For this analysis, we consider all Italian consonants independently of their syllabic position (e.g., syllable onset or coda). Table 2 shows the frequency of occurrence summing across positions according to token and type frequency. Type frequency counts how many times a phoneme occurs in words of the language, with each word counted only once. Token frequency, instead, counts how often a phoneme occurs in the language overall, with each word in which the phoneme occurs multiplied by its frequency. There were significant correlations between these frequency measures, acquisition measures and the errors of individuals with AoS.

Pearson *r* correlations of *raw Italian phoneme frequency* with *child phoneme acquisition* were, *for type frequency*: .57, .50, and –.72; *for token frequency:* .63, .53, and −.78 **(**for word initial, word medial, and overall acquisition rank, respectively). Pearson *r* correlations of *raw Italian phoneme frequency* with *AoS errors* were for *type frequency*: −.51; for *token frequency*: −.53 (all correlations were significant, $p \leq .001$ to .01).

Pearson *r* correlations of *log Italian phoneme frequency* with *child phoneme acquisition* were, *for type frequency*: .77, .56, and –.83; *for token frequency:* .76, .64, and −.86 **(**for word initial, word medial, and overall acquisition rank, respectively). Pearson *r* correlations of raw *log Italian phoneme frequency* with *AoS errors* were for *type frequency*: −.53; for *token frequency*: −.43 (all correlations were significant, $p \leq .001$ to .01).

Finally, Pearson *r* correlations of *AoS errors* and child *phoneme acquisition* were: .40, .48, and .58 (for word initial acquisition, word medial acquisition, and overall acquisition, respectively, with $p = .06$, .03, 01).

Our results show that the higher the frequency of a consonant, the earlier it is acquired by children and the better it is preserved in individuals affected by apraxia of speech. These associations indicate that our empirical measures work well and tap some common underlying variables. There are, however, several notable exceptions to this pattern that can be seen right away. The aphasic participants make a particularly high number of errors on all voiced consonants (e.g., /b/, /g/, /d/, /v/, g/, which were produced devoiced). The consonant /r/ has high frequency, but it is acquired late and elicits many errors; similarly, /ts/ is acquired later and elicits more errors than expected on the basis of its frequency. These discrepancies suggest that another variable—for example, markedness—may overwrite frequency. In the following sections, we analyse the relation between different markedness contrasts on the one side and frequency, AoA, and AoS errors on the other. Consonant frequency may be strongly dependent on position for some consonants. In particular, the frequency of liquids (/r/ and /l/) may be boosted by the fact that they can occur over a range of different syllabic positions, whilst other consonants, such as /t/, can only occur in onset. To avoid any potential confounding, frequency measures in the following analyses are restricted to consonants in simple onsets.

3.2. Markedness, frequency, AoA, and AoS

Here, we consider the association between markedness and phoneme frequency, AoA, and AoS errors. We consider markedness in terms of main contrasts in articulation manner, place of articulation, and voicing. The markedness rankings we use are well accepted in the linguistic literature, but we begin each section by a brief outline of the relevant existing cross-linguistic and developmental evidence in their favour. Note that, in Italian, these contrasts are independent and orthogonal with one another. For example, contrasts in place occur across consonants of the same manner, and contrasts in voicing occur across consonants of the same manner and place. Therefore, knowing the ranking of consonants of different manner tells us nothing of their ranking according to place or voicing.

3.2.1. Consonants contrasting by manner

There is consensus that, among obstruents, stops characterized by the feature – *continuant* are unmarked compared to fricatives characterized by the feature + *continuant* (e.g., see Greenberg, 1978, 1966/2005). Affricates are still more complex and are sometimes described as the sequence of a stop plus a fricative, although they behave as single segments. They are often characterized by the marked feature + delayed release. /tʃ/ and /ʤ/ are present in only 141 and 80 languages, respectively, of the 317 languages surveyed by Maddieson (1984), while /ts/ and /dz/ are present in even fewer languages: only 95 and 30, respectively (see also Celata, 2004; Costamagna, 2008). Among sonorants, nasals have a wide distribution (Maddieson, 1984); lateral liquids have a wider distribution than rhotics (57% of liquid sounds in the word languages are laterals; see Maddieson, 1984).

Developmental results also suggest that nasals are relatively easy to produce compared to liquids, especially /r/. Studies on *English* acquisition have shown the predominance of stops, nasals, and glides in the early vocabulary of children (see the seminal studies of Ingram, 1981; Stoel-Gammon, 1985; Winitz & Irwin, 1958, and the longitudinal studies of Menn, 1971; Vihman, Macken, Miller, Simmons, & Miller, 1985). Studies on *Dutch* and *German* acquisition have confirmed the early acquisition of stops especially over fricatives (see Altvater-Mackensen & Fikkert, 2010; Grijzenhout & Joppen-Hellwig, 2002; Kager et al., 2007). A large study like that of the Iowa-Nebraska Articulation Norms Project (Smit, Hand, Freilinger, Bernthal, & Bird, 1990) with over 1000 children between 2 and 9 years of age has confirmed these trends (see also Priester, Post, & Goorhuis-Brouwere, 2011, for a review of studies comparing English and Dutch). Nasals were acquired very early together with stops, while affricates and liquids were acquired much later, with /r/ being acquired especially late. Fricatives were in between (excluding /θ/ and /ð/, which are very complex).

The same trends as those shown in other languages are evident in Italian children. Zmarich and Bonifacio (2005) showed that stops and nasals were acquired before other categories of sounds; /p/, /t/, /k/, /b/, /d/, /m/, /n/ were all attested by 21 months, while the fricatives /f/, /v/, /s/ were attested only by 24 months. Stops and nasals were all consolidated by 24 months, while none of the fricatives was consolidated by 27 months. Affricates were acquired later. /ʧ/ was attested by 21 months, but not yet consolidated by 27 months; /ʤ / was not even attested by 27 months; /ts/ and /dz/ were not considered target consonants in the study because of their low frequency. Among liquids, there was a great disparity in the acquisition of /l/ and /r/. /l / was already consolidated within words by 21 months and attested in word-initial position by 24 months, while /r/ was neither attested nor consolidated in any position by 27 months. Zanobini et al. (2012) showed similar trends to those of Zmarich and Bonifacio (2005): an earlier acquisition of voiceless stops, nasals, and the liquid /l/, followed by fricatives (except /s/, which was acquired early), followed by voiced stops and /r/, followed by affricates.

3.2.1.1. Results for consonants contrasting by manner.

Table 3 shows frequency statistics for consonants in simple onsets organized by manner together

Table 3. Frequency, AoA, and AOS errors for consonants in simple onsets contrasting in manner.

Markedness rank	Manner	TokenFreq. log	AoA rank	AoS errors N	AoS errors %
Obstruents					
1	*Stops*				
	t	5.94	**1**	162	2.0
	d	5.74	**3**	353	14.1
	k	5.66	**1**	201	5.1
	p	5.47	**2**	132	4.5
	b	4.99	**3**	199	14.1
	g	4.73	**5**	236	28.6
	Mean	**5.42**	**2.5**	1283	**6.4**
2	*Fricatives*				
	s	5.68	**2**	195	6.5
	v	5.43	**3**	390	19.2
	f	5.15	**4**	203	10.2
	ʃ	4.42	**5**	30	21.6
	Mean	**5.17**	**3.5**	818	**11.4**
3	*Affricates*				
	ʧ	5.17	**3**	139	8.2
	ʤ	4.99	**5**	181	21.5
	ts	4.7	**6**	37	19.2
	dz	4.15	**6**	154	18.1
	Mean	**4.75**	**5**	511	**14.3**
Sonorants					
1	*Nasals*				
	n	5.73	**2**	190	4.2
	m	5.56	**2**	133	4.0
	ɲ	4.39	**5**	44	36.1
	Mean	**5.23**	**3**	367	**4.6**
2	*Liquids*				
	l	5.69	**1**	273	6.1
	r	5.67	**3**	411	8.8
	ʎ	4.65	**5**	67	21
	Mean	**5.34**	**3**	751	**7.9**
3	*Glides*				
	w	3.99	**4**	12	21.4
	j	3.56	**4**	28	11.2
	Mean	**3.78**	**4**	40	**13.1**

Note: AoA = age of acquisition; AoS = apraxia of speech; TokenFreq. = token frequency;. Error rates for patients with AoS include geminate phonemes.

with markedness ranks, acquisition ranks, and AoS errors. For brevity, in these and subsequent tables we report only log token frequencies.

The correspondence between frequency, AoA, and errors in AoS remains very high when we restrict our consideration to frequency in simple onset. Pearson's *r* correlations between token RAW frequency and AoA rankings: −.82, $p < .001$; and AoS errors: −.71, $p < .001$. Correlation between LOG frequency and AoA: −.77, $p < .001$; and AoS errors: −.64, $p < .001$. Correlation between AoS and AoA: .80, $p < .001$.

Since there are only few contrasts in manner, statistical analyses are difficult, but we can still consider whether or not there are qualitative correspondences in the rankings. Among obstruents, the correspondence between markedness, frequency, AoA, and AoS is perfect. Stops have the highest frequency, are acquired first, and elicit the lowest error rates in AoS, while fricatives are second and affricates last. Among sonorants, instead, correspondences break down; nasals are less marked than liquids, which, in turn, are less marked than glides.[3] This markedness hierarchy is respected by AoS errors, but not by frequency or AoA, since nasals and liquids have similar frequency and acquisition rank. Also note that the liquid /r/ is considered more marked than /l/. Accordingly, /r/ is acquired later and elicits more AoS errors than /l/ [for AoS errors: $\chi^2(1) = 24.6$, $p < .001$]. However, /r/ and /l/ have similar frequency. These results indicate that the frequency of phonemes in the language is less tightly constrained by markedness principles than children's and aphasic productions. Markedness may be related more strongly to AoA and AoS errors because it reflects articulatory difficulties that are present in these populations.

3.2.2. Consonants contrasting by place

Italian plosive consonants contrast for place of articulation and, thus, provide the ideal context to examine this feature. Of the six Italian plosives, two have a bilabial place of articulation (/p/ and /b/), two have an alveolar place (/t/ and /d/), and two have a velar place (/k/ and /g/). Moreover, Italian has three palatalized consonants produced with the body of the tongue raised against the hard palate. These are: /ɲ/ among nasals (as in "gnocchi"), /ʎ/ among liquids (as in "aglio"), and /ʃ/ among fricatives (as in "asciugamano"). There is consensus that coronal segments (including dental and alveolar place of articulation) are more widely distributed across languages and should be considered unmarked (e.g., Paradis & Prunet, 1991). However, cross-linguistic results also show an interaction between voicing and place. The consonant /t/ is clearly the most widely distributed segment, and /g/ is more widely distributed than /b/, as predicted by a marked place of articulation. However, for reasons that are not clear, /k/ is actually more widely distributed than /p/ (see Maddieson, 1984).

Developmental results are generally consistent with cross-linguistic rankings. In the study by Stoel-Gammon (1985), anterior consonants (coronals and labials) were acquired before dorsal consonants by English children. Similarly, in the study by Kager et al. (2007) with Dutch, German, and English children, dorsal consonants produced significantly more errors than labials and coronals, which elicited similar error

Table 4. Frequency, AoA, and AoS errors for consonants in simple onsets contrasting in place.

Manner	Place	Markedness rank for place	Onset phones	TokenFreq. log	AoA rank	AoS errors	
						N	%
Stops	Alveolar	1	t/d	5.85	2	515	**4.8**
	Bilabials	2	p/b	5.30	2.5	331	**7.6**
	Velars	3	k/g	5.41	3	437	**9.1**
Nasals	Alveolar	1	n	5.73	2	190	**4.2**
	Bilabials	2	m	5.56	2	133	**4.0**
	Palatal	3	ɲ	4.39	5	44	**36.1**
Fricatives	Alveolar	1	s	5.68	2	195	**6.5**
	Bilabials	2	f/v	5.31	3.5	593	**14.7**
	Palatal	4	ʃ	4.42	5	30	**21.6**
Liquids	Alveolar	1	r/l	5.68	2	684	**7.5**
	Palatal	4	ʎ	4.65	5	67	**21.0**

Note: AoA = age of acquisition; AoS = apraxia of speech; TokenFreq. = token frequency. Values are averages when there are two segments in a category. Acquisition ranks are from Zanobini et al. (2012). For AoS errors, measures include geminate phonemes.

rates; voiced velars were particularly difficult for Dutch children. The same pattern was noted with Italian children. Zmarich and Bonifacio (2005) reported that /p/ and /b/ and /t/ and /d/ were consolidated before /k/ and /g/ and that /g/ was acquired particularly late since it was not yet consolidated by 27 months (see also Bortolini et al., 1995, which showed that /g/ started to be produced only by 21 months). Zanobini et al. (2012) partially confirmed this pattern because they showed a very late acquisition of /g/, but an early acquisition of /k/, acquired between /t/ and /p/, consistent with the cross-linguistic distribution. Finally, Italian developmental studies have highlighted the difficulty of acquiring palatalized sounds. The consonants /ɲ/, /ʎ/, and /ʃ/ were mostly produced after 27 months according to Zmarich and Bonifacio (2005) and were produced by very few children aged 36–42 months according to Zanobini et al. (2012).

3.2.2.1. Results for consonants contrasting by place. Results are presented in Table 4 (Zanobini et al., 2012) There is an excellent correspondence between markedness rankings, frequency, AoA, and errors of patients with AoS. Alveolar segments are the most frequent, acquired earliest, and eliciting the least number of errors in patients with AoS. Among stops, velars are the least frequent, are acquired last, and produce the highest error rates in AoS. Palatal segments are the least frequent of all, acquired last, and elicit the highest error rates in patients with AoS (for apraxic errors, all differences between alveolar and either velar or palatal sounds are significant: $\chi^2(1) = 45.2–250$, all $p < 001$). The range of acquisition ranks is too small to allow individual comparisons, but the patterns show perfect consistency.

It is to be noted, however, that an average value for velars masks a strong difference between voiced and unvoiced segments (see Table 5). It is only /g/ that is infrequent, acquired late by children, and error prone in AoS. The segment /k/, instead, is more frequent than /p/ (consistent with cross-linguistic results), is acquired early, and is not particularly difficult for patients with AoS. Consistent with this pattern, among errors involving unvoiced stops, /t/ is the segment used most often as a replacement in errors [**/t/**: 93/6179 = 1.0%; /p/: 60/9870 = 0.61%; **/k/**: 66/8971 = 0.74%; /t/ vs. /p/, $\chi^2(1) = 31.4$, $p < .001$; /t/ vs. /k/, $\chi^2(1) = 20.1$, $p < .001$; /p/ vs. /k/, $\chi^2(1) = 1.2$, *ns*].[4]

3.2.3. Consonants contrasting by voicing

Voicing is a contrasting feature within plosives (/p, t, k/ vs. /b, d, G/), fricatives (/f/ vs. /v/), and affricates (/ʧ, ts/ vs. /ʤ, dz/). Cross-linguistic evidence shows that the feature + *voiced* should be considered marked since voiced segments are systematically less widely distributed than corresponding unvoiced segments (e.g., Greenberg, 1966/2005; Maddieson, 1984). However, as we have discussed, voicing has a different connotation in different languages, and this is associated with different results. For example, Stoel-Gammon (1985) reported that *voiced* stops are acquired before voiceless stops by English children, while Italian, Spanish, and French show the opposite trend (see for Italian: Bortolini et al., 1995; for Spanish: Aram, Hack, Hawkins, Weissman, & Borawski-Clark, 1991; for French: Allen, 1985). Moreover, children acquiring aspirated languages substitute voiced for voiceless stops while children acquiring voice-led languages show the opposite pattern (for a review see Kager et al., 2007). This may suggest that starting vibration of the vocal cords *immediately after* release of the

Table 5. Frequency, AoA, and AOS errors for consonants in simple onsets contrasting in voicing.

Manner	Place	Voicing	Markedness rank for voicing	Onset phones	TokenFreq. log	AoA rank	AoS errors	
							N	%
Stops	alveolar	voiced	1	t	**5.94**	1	162	2.0
		unvoiced	2	d	5.74	3	353	**14.1**
	bilabials	voiced	1	p	**5.47**	2	132	4.5
		unvoiced	2	b	4.99	3	199	**14.1**
	velars	voiced	1	k	**5.66**	1	201	5.1
		unvoiced	2	g	4.73	5	236	**28.6**
Fricatives	voiced	unvoiced	1	f	5.15	4	203	10.2
			2	v	**5.43**	3	390	**19.2**
Affricates	voiced	unvoiced	1	ʧ	**5.17**	3	139	8.2
			2	ʤ	4.99	5	181	**21.5**

Note: AoA = age of acquisition; AoS = apraxia of speech; TokenFreq. = token frequency. Error rates in AoS include geminate phonemes.

articulatory closure (as in Italian unvoiced and English voiced stops) is preferred than starting it either *before release* (Italian voiced stops) or *a long interval after release* (English unvoiced stops). Another possibility is that aspiration adds difficulty to the production of unvoiced stops in English with + spread glottis being a marked feature. Aspiration will make English unvoiced consonants as marked as or more marked than their voiced counterparts.

Results from aphasia are not as clear-cut, but there seems to be a more general tendency to produce devoicing errors across languages (for Italian see Romani & Calabrese, 1998; Romani & Galluzzi, 2005; for Portuguese see Cera & Ortiz, 2010; for English, see Blumstein et al., 1980; Tuller, 1984; but also see Mauszycki, Dromey, & Wambaugh, 2007, for a contrasting case). Possibly, the articulatory impairments associated with aphasia mean that a long delay in vocal cord vibration is always preferred. Instead, children may struggle to acquire the range of values that are right for their language and produce VOT with more intermediate values, which will result in devoicing errors in Italian, but in voicing errors in English. In spite of this cross-linguistic uncertainty, markedness ranking for Italian, which is a voice-led language, is clear: Voiced segments are more marked.

Table 6. Results of stepwise linear regression analyses predicting either age of acquisition ranks or rates of errors in patients with AoS.

		Adj R^2	*R* change	*F* chance	*p*
AoA	*Manner*				
	TokenFreq.	.80		77.6	<.001
	Place				
	Mark-rank	.86		64.8	<.001
	Mark-rank + Err-AoS	.92	.06	7.96	.02
	Voicing				
	Err-AoS	69.3	.002	21.3	.002
	All data				
	TokenFreq.	.74		116.5	<.001
	TokenFreq. + Err-AoS	.81	.07	14.7	<.001
AoS	*Manner*				
	AoA-rank	.64		35.2	<.001
	AoA-rank + Mark-rank	.72	.09	6	.02
	Place				
	AoA-rank	.82		45.9	<.001
	Voicing				
	AoA-rank	.69		21.3	.002
	AoA-rank + Mark-rank	.87	.173	12.1	.01
	All data				
	AoA-rank	.70		92.7	<.001

Note: AoA = age of acquisition; AoS = apraxia of speech; TokenFreq. = token frequency; adj = adjusted; err = error. Predicted variables entered: token log frequency, markedness rank, and either AoA rank or AoS error rate (depending on which is the dependent variable).

3.2.3.1. Results for consonants contrasting by voicing.

Table 5 shows results for consonants that contrast in voicing. Markedness is consistent with error rates in AoS. Voiced consonants always elicit more errors. It is also consistent with frequency and AoA in four out of five pairs. Fricatives are an exception because /v/ is more frequent than /f/, and it is acquired earlier by children. Thus, here, only patients with AoS follow what is predicted by markedness (cross-linguistically, /v/ has a more limited distribution than /f/; Maddieson, 1984). Patients with AoS not only make more errors on /v/ than /f/ but also make more errors changing /v/ into /f/ than vice versa [v > f: 177/2958 = 6.0%; f > v: 38/3005 = 1.3%; $\chi^2(1) = 95.5$, $p < .001$].

The contrast between /v/ and /f/, together with the strong difference between /g/ and /k/ noted above, suggests that voicing difficulty is modulated by both manner and place of articulation. Voicing may be easier for fricatives that are produced with an incomplete constriction and air turbulence. A more modest difference in complexity between /f/ and /v/ would allow /v/ to become more frequent in the adult language, and this, in turn, would promote its earlier acquisition. In addition, voicing may be particularly difficult for velars because it is difficult to keep air flowing through the glottis and make vocal cords vibrate with a velar constriction (see Kingston, 2007). Consistently, /g/ is missing in some languages, such as Dutch or Thai, and, in patients with AoS, the difference between voiced and unvoiced segments is higher for velars (23.5%) than for either bilabials (9.7%), $\chi^2(1) = 47.3$, $p < .001$, or alveolar (12.2%), $c^2(1) = 38.0$, $p < .001$, and devoicing errors occur more often for /g/ (474/1659 = 28.6%) than for either /b/ (255/2077 = 12.3%), $\chi^2(1) = 155.9$, $p < .001$, or /d/ (357/2284 = 12.4), $\chi^2(1) = 96.7$, $p < .001$.

3.2.4. Discussion

Taken together, the results across manner, place, and voicing show that there is a good correspondence between all the four variables: markedness, frequency, AoA, and AoS. However, there are also some discrepancies pointing to some independence between markedness and frequency. Markedness is more strongly associated with errors in AoS—an indication of articulatory difficulty—than with frequency in the language. Markedness hierarchies are followed by AoS errors but not by frequency for some contrasts in place (differences between nasals and liquids, and /r/ and /l/ in AoS errors but not in frequency) and in voicing (differences between /v/ and /f/ in AoS errors, but opposite differences in frequency). Moreover, while AoS errors always follow markedness ranking, AoA sometimes follows markedness and other times frequency. Children acquire /r/—more marked—later than /l/—less marked—despite the fact that these phonemes have similar frequency in the language. Instead, following frequency, they acquire /v/ earlier than /f/, despite the fact that /v/ is more marked.

3.3. Relative contributions of markedness and frequency to AoA and AoS

To assess the relative contribution of different variables to AoA and AoS errors, we ran a series of regression analyses with either AoA or AoS errors as the dependent variables and markedness, frequency, and AoA/AoS errors (depending on the analyses) as the independent variables. Analyses were carried out using SPSS: linear regression, stepwise, forward method. All variables were entered together. The significance of the variable making the strongest contribution was assessed first. The independent contribution of the other variables was then assessed, with the variable making the strongest contribution always considered first.

We carried out four analyses: (a) by manner (with markedness rankings as follows: stops = 1; fricatives = 2; affricate = 3; nasals = 1; liquids = 2); (b) by place (with markedness ranking as follows: coronal = 1; bilabial = 2; velar = 3; palatal = 4); (c) by voicing (with markedness ranking as follows: voiced = 1 and unvoiced = 2); and (d) considering all contrasts together. Results are shown in Table 6. AoA is predicted by frequency (for manner and when all results are considered together) but also by AoS errors and markedness ranking, which make independent contributions. In other words, age of acquisition is predicted both by how frequently children are exposed to certain phonemes and practise their production and by complexity (indexed by markedness ranking and apraxic errors). In contrast, AoS errors are predicted by AoA rank and markedness rank, but not independently by frequency. In other words, frequency does not make an independent contribution over and beyond AoA and markedness ranks. The fact that frequency, markedness, AoS errors, and AoA make independent contributions is not surprising, since they are different measures even if they tap some common underlying factors. What is more significant is the fact that frequency makes a stronger contribution to explain AoA than AoS errors.

3.4. Summary of results and contrast between aphasic groups

The strong association between markedness and AoS errors suggests that markedness constraints are underpinned by differences in articulatory complexity. In this section, we wanted to provide further evidence by contrasting aphasics with AoS with aphasics with more central phonological difficulties. In previous papers, we have shown that apraxic and phonological aphasics contrast in terms of rate of simplification errors (i.e., AoS individuals make many more simplifications—where the errors result in a phoneme less marked than the target—than complications—where the errors result in a phoneme more marked than the target; phonological aphasics, instead, make similar rates of simplifications and complications; e.g., see Galluzzi et al., 2015).

Table 7. Overall frequency, age of acquisition, and aphasic error rates for phonological category/segments contrasting in markedness.

	TokenFreq.			AoS aphasics					Phonological aphasics				
	Raw	Log	AoA	*N* err	*N* stim	% err		*p*	*N* err	*N* stim	% err		*p*
Stops	388,004	5.42	2.5	1283	19,907	**6.4**	+	<.001	544	19,384	**2.8**	+	<.001
Fricatives	228,124	5.17	3.5	818	7154	**11.4**			275	6717	**4.1**		
							+	<.001				−	*ns*
Affricates	77,643	4.75	5	511	3576	**14.3**			124	3220	**3.9**		
Nasals	309,652	5.23	3	367	7917	**4.6**	+	<.001	246	7702	**3.2**	−	*ns*
Liquids	334,219	5.34	3	751	9494	**7.9**			256	9261	**2.8**		
l	491,922	5.69	1	273	4499	**6.1**	+	<.001	146	4404	**3.3**	−	*ns*
r	465,885	5.67	3	411	4676	**8.8**			105	4547	**2.3**		
Alveolars	552,185	5.74	1.6	515	10,749	**4.8**	+	<.001	300	10,422	**2.9**		
Bilabials	254,934	5.39	2.7	331	4373	**7.6**	+	<.001	123	4280	**2.9**		
												−	*ns*
Velars	257,329	5.41	3	437	4785	**9.1**	+	<.001	121	4692	**2.6**	+	*ns*
Palatal	18,356	4.49	5	141	580	**24.3**			14	487	**2.9**		
Unvoiced	381,667	5.48	2.2	837	18,862	**4.4**	+	<.001	474	18,104	**2.6**	+	<.001
Voiced	214,326	5.18	3.8	1359	7604	**17.9**			324	7396	**4.4**		
Total errors				**8074**					**3082**				

Note: AoA = age of acquisition; AoS = apraxia of speech; TokenFreq. = token frequency; err =errors; stim = stimuli. Age of acquisition = acquisition rank. The *p* values refer to χ^2 differences between types of phonemes.

Here, we wanted to assess error rates out of number of stimuli for the eight markedness contrasts already examined: four involving manner [(a) stop vs. fricatives, (b) fricatives vs. affricates, (c) nasals vs. liquids, (d) among liquids, /l/ vs. /r/]; three involving place [(a) alveolar vs. bilabial, (b) bilabials vs. velar, and (c) velar vs. palatal] and one involving voicing (voiced vs. unvoiced). For each contrast, differences in error rates between individuals with AoS and phonological difficulties have been assessed through χ^2 analyses. Results are shown in Table 7.

In all of the eight examined contrasts, individuals with AoS made more errors on the marked member of the pair. In contrast, the individuals with phonological impairments showed significant differences in only two contrasts (e.g., more errors on fricatives than stops and on voiced than unvoiced consonants). Moreover, while they made generally fewer errors than individuals with AoS, differences between the two groups were modest in the baseline conditions, but very strong in the marked conditions. Finally, while the errors of individuals with AoS were strongly correlated with age of acquisition ($r = .82$, $p = .001$), the errors of individual with phonological impairments showed no significant correlation ($r = .37$, $p = .21$). Similarly, correlations with frequency were significant in the AoS group but failed to reach significance in the phonological group ($r = .80$, $p = .001$; $r = 42$, $p = .15$). These results together suggest that the association between markedness, AoA, and aphasic errors is mediated by the fact that all of these variables are influenced by articulatory complexity.

Table 7 also reports results for frequency and AoA, to provide a general overview of our results. Considering all our variables together (markedness, frequency, AoA, and AoS errors) there is a very strong inter-correspondence with results in the expected direction in 30/32 of the contrasts examined (8 contrasts × 4 variables: markedness, frequency, AoA, AoS errors). The probability of this happening by chance is vanishingly small ($p < .000001$), indicating a strong association among our measures and between these measures and cross-linguistically derived markedness rankings.

4. General discussion

4.1. Effects of markedness and frequency in speech production

We examined the associations between cross-linguistic markedness principles and three empirical variables related to the frequency with which phonemes occur in their language, their AoA, and the ease with which they are produced by individuals with AoS. These allow insights into the nature of possible universal principles of complexity and their relation to frequency of use in the language. We found a strong relation across these variables and, in particular, a good association between markedness on the one side and frequency, AoA, and AoS errors on the other. This result indicates that markedness is an important variable affecting phoneme production. The correspondences, however, were not perfect, suggesting the contribution of independent effects of markedness and frequency.

First of all, correspondences between markedness and AoS errors were particularly strong. Among obstruents, progressively more errors were made on plosives, fricatives, and affricates. Among sonorants, more errors were made on liquids than on nasals, and for liquids, on /r/ than on /l/. Voiceless consonants elicited fewer errors than voiced consonants, and there were many more devoicing than voicing errors across consonants of all manners. Velar segments were also found to elicit more errors than alveolar and bilabial segments, with palatal segments the most difficult of all. These correspondences are striking since markedness rankings are derived from completely different data—that is, considering the distribution of segments in the languages of the world, the domain of application of linguistic rules, and implicational universals (Greenberg, 1978; Jakobson, 1941/1968; Maddieson, 1984). In contrast, phonological aphasics who make perceptually similar kinds of phonological errors, but without evidence of apraxia of speech, showed much weaker and insignificant associations with markedness rankings and AoA measures.

Frequency distributions also followed markedness, but with a few exceptions. As expected, among obstruents, plosives were the most frequent consonants, followed by fricatives and then affricates. Among sonorants, however, nasals and liquids have similar frequency, and among liquids, /l/ was *not* more frequent than /r/. As expected, an alveolar place of articulation was used most often and a palatal place least often. Also, as expected, voiceless consonants were generally more frequent than their voiced counterparts, but fricatives showed the opposite pattern. These exceptions are important because they show the relative independence of frequency and complexity.

Age of acquisition showed an intermediate pattern. In two cases, results lined up with frequency against what was predicted by markedness and AoS: (a) /v/ was acquired earlier than its unvoiced counterpart /f/; (b) the velar /k/ was acquired earlier than the labial /p/. In another two cases, AoA results lined up with complexity (defined by markedness ranking and AoS errors) against frequency. The liquid /r/ was acquired later than nasals in spite of its high frequency. The affricate /ts/ was one of the segments acquired last in spite of its intermediate frequency rank. These results show that frequency of input can speed up AoA (see also Altvater-Mackensen & Fikkert, 2010, for a discussion for Dutch), but, equally, that complexity can delay acquisition, in spite of frequency.

Results from the developmental literature also show that AoA can be modulated by *both* frequency and markedness. Velleman and Vihman (2007) noted that, across languages, children in their early speech often produce long consonants (geminates) because slow articulation promotes their production. Later on, however, (after a vocabulary of 50 words is reached) production becomes modulated by frequency of occurrence in the language so that geminates disappear in English and French, begin to be used appropriately in Welsh, and are overused in Finnish and Japanese. Other results show that markedness can delay acquisition, in spite of frequency. In Dutch, children acquire voiceless consonants before the voiced counterparts, which is consistent with markedness, but contrary to frequency since voiceless segments are less frequent than voiced segments in Dutch (Kager et al., 2007). It is interesting, however, that results contrary to markedness ranking always involved contrasts where differences in complexity were small. Voicing may be easier in fricatives than in plosives because vibration of the vocal cords is easier when there is not a complete constriction of the vocal tract. This allows /v/ to become more frequent than /f/ in the adult language and to be acquired earlier by children. Instead, starting vibration of the vocal cords is particularly difficult with a posterior, velar point of constriction, explaining the strong differences between /g/ and /k/.

4.2. Nature of complexity effects and aphasic patterns

In the late sixties, Jakobson (1941/1968) articulated in the most eloquent way what is known as the regression hypothesis (already advocated by others such as Jakobson and Ribot). According to this hypothesis, the same principles as those that drive language acquisition and the distribution of phonemes across and within languages also apply to language loss. Thus, individuals with aphasia should produce more errors on those structures that are acquired late by children and that are less frequent within and between languages. This hypothesis was dismissed early on as a *general* explanation for aphasia (e.g., Albright, 1958; Caramazza, 1994). It has been noted that aphasic errors do not systematically affect some (more complex) structures compared to others. Instead, double dissociations are common. For example, some aphasic individuals have trouble with nouns, but not verbs, while others show the opposite pattern; some individuals have trouble with content words, but not with function words and syntactic structures (anomic), while others show the opposite pattern (agrammatic), and so on (see Caramazza, 1994, for a clear articulation of these arguments). These observations, however, have been over-interpreted.

We would argue that complexity is not an explanatory dimension in the case of impairments affecting *representations*—brain damage may selectively affect some representations, sparing others without a systematic direction—but it is a crucial dimension in the case of impairments affecting *processing resources*. Complex processes require more resources because they involve operations that are more numerous, time consuming, precise, and/or context dependent. Since brain damage can reduce, but not increase, resources, it should *always* affect complex processes more than simple ones. This means that individuals with a reduction in articulatory resources will always have more difficulty with complex/marked phonemes (and complex syllables, although not the focus here). No individual should show an anti-complexity effect, but aphasics with no difficulties in articulation may show reduced or absent complexity effects since, for them, articulatory resources are not an issue. These individuals, instead, may suffer from representational impairments where the information that allows picking the right phonemes for words is lost. Thus, they may select between close alternatives, but without a systematic direction in which alternative is picked (see Galluzzi et al., 2015, and also Romani & Galluzzi, 2005; Romani et al., 2011).

Our results and the explanation we are proposing in part vindicate Jakobson's (1941/1968) original claims, but also depart from them in substantial ways. Jakobson strongly opposed the idea that phonological development (and aphasic errors) is driven by a principle of articulatory complexity or by a "*principle of least effort*". His main argument was that during babbling children produce all sorts of sounds, even very complex ones, which they are unable to produce later on. This would demonstrate that the fixed order in which phonemes are acquired is not due to increased articulatory proficiency since this proficiency is present very early on. Instead, order of emergence would reflect the stratified structure of language where simpler, more undifferentiated "layers" need to be acquired before further, more complex ones. Therefore, for Jakobson, markedness does not refer at all to articulatory complexity, but to the number of abstract contrasts represented at a given layer. Children and aphasic individuals will have simpler/less differentiated grammars representing fewer distinctions.

There are a number of problems with Jakobson's (1941/1968) account. First of all, he does not distinguish between different types of aphasia, and, thus, he confuses the two patterns we have described. At some point in his book, he talks of *losing* differentiating features, so that aphasics produce one or the other of two phoneme variants without systematicity (he gives the example of /r/ and /l/). In other places, he talks to reverting to the simpler/more basic versions of phonemes in a systematic way (e.g., using plosives instead of fricatives). We have shown that these two patterns characterize different individuals and should not to be conflated. Secondly, by opposing an articulatory underpinning of complexity principles, Jakobson leaves unmotivated *why* some contrasts are simpler than others; if we do not invoke articulatory principles, there is no reason why, for example, plosives should be easier than fricatives. Finally, Jakobson is likely to have overestimated the articulatory abilities shown by children at the babbling stage. It is likely that the production of complex sounds at this stage occurs accidentally, while the articulators are tested, and is not an indication of articulatory control.

The contrast provided by different types of aphasia (contrary to Jakobson, 1941/1968) supports theories that see phonological constraints and universal principles of complexity as grounded in articulation (e.g., Bermúdez-Otero & Börjars, 2006; Kingston, 2007) and are contrary to views that see these principles as abstract (e.g., Hale & Reiss, 2000). If complexity principles were abstract or a reflection of frequency in the language there would be no reason for correspondences to be so strong in aphasic individuals with articulatory difficulties but not in other aphasic individuals making similar types of phonological errors.

The implications of our results are summarized in the following section.

4.3. Implications

4.3.1. Support for markedness universals

Our results show a strong correspondence of effects across domains. Although our measures of phoneme acquisition, phoneme loss, and phoneme frequency are intrinsically noisy and are collected using completely different methodologies, correspondences were remarkable, indicating that markedness constraints are central to different aspects of language. Our results in the production domain are consistent with evidence of universal phonological principles in the perceptual domain (e.g., see Berent, 2013a, 2013b).

4.3.2. Markedness and frequency: Related but independent variables

Adult languages need to use a variety of different phonemes—including complex ones—to encode a sufficient number of diverse words. This may predict only weak correspondences between frequency and complexity. In contrast, our results demonstrate that markedness principles continue to shape adult language, not only by prohibiting certain phonemes, but, more pervasively, by affecting their distributions (see also Piantadosi et al., 2012). Frequency and markedness, however, are not simply reflections of each other. Instead, our results indicate that they contribute independently to shape speech production. While markedness rankings are perfectly reflected in the errors of individuals with AoS, they are less well reflected in the distribution of phonemes in the adult language. Moreover, which phonemes are acquired first by children is sometimes more influenced by markedness and other times more influenced by frequency. If markedness was simply a consequence of frequency, it would be reflected in the same way in adult frequency, acquisition measures, and apraxic errors. Therefore, our results broadly support modern views where phonology is shaped by two competing forces: innate principles of complexity and idiosyncratic choices made by the community of adult speakers to expand their lexicon (see Hayes et al., 2004; Prince & Smolensky, 2004). This flexible relation between complexity and frequency is responsible for the variability and richness of human languages.

4.3.3. Markedness is based on articulatory complexity

Our results support the idea that principles of complexity have an articulatory basis since they selectively affect aphasic individuals with independent evidence of apraxic difficulties (e.g., see Bermúdez-Otero & Börjars, 2006). This suggests that complexity effects can be a diagnostic tool to distinguish phonological impairments from apraxia of speech (see Galluzzi et al., 2015).

4.3.4. Characterizing the phonological/articulatory interface

Finally, our results underscore a difference between representational and processing impairments at the interface between phonology and articulation (see Avrutin, Haverkort, & van Hout, 2001, for a general discussion of this dichotomy in acquisition and aphasia). In some incarnation or others, a dichotomy between representations and processes has been used to explain what is impaired in amnesia (e.g., Squire, 2004), in specific language impairments (see Gopnik, 1990 vs. Montgomery & Windsor, 2007), and even, recently, in developmental dyslexia (Ullman & Pierpont, 2005). In the realm of aphasia, the debate over whether impairments involve representations or processing resources has mainly involved agrammatism and sentence comprehension (e.g., see Kolk, 1995, 2011), not phonology. We have argued that in the phonological domain, like in other domains, impairments can affect either representations or processes, and that markedness constraints are fundamental to understanding processing impairments that involve programming of articulation.

4.4. Conclusions

Currently there is a strong debate regarding whether we need to hypothesize universal, innate principles as the basis of human language (e.g., see Berent, 2013a, 2013b; Evans & Levinson, 2009). In Italian, we have shown a strong correspondence between markedness rankings (cross-linguistically derived) and rates of errors made by aphasic individuals with articulatory difficulties. These complexity measures were also strongly associated with age of acquisition and frequency, although they were partially independent from frequency. Our results support the existence of universal articulatorily grounded principles of complexity. Whether these principles are used in a formalized way by linguistic rules or they are just a consequence of the physical properties of speech remains to be determined. It is clear, however, that they are strong determinants of linguistic behaviour and deserve a central place in any explanation.

Notes

1. Note that it is phonological features and not phonemes that are marked or unmarked. Phonemes are commonly conceived as bundles of features; each feature has a binary value: marked or unmarked. Thus, phonemes may combine marked and unmarked features.
2. In a given language, phonemes can have allophonic variants that involve different pronunciations, but are not contrastive (they do not distinguish words with different meanings). The basic allophone is the one that is used in more contexts.
3. Note that the difficulty of glides is hard to evaluate. They are easy to articulate, but they provide a limited sonority contrast with the following vowel. This last feature can explain why they are infrequent, acquired late, and elicit high error rates in patients with apraxia of speech.
4. The same analyses cannot be run among voiced segments because, here, errors are systematically devoicing errors, with very few errors changing place of articulation.

Disclosure statement

No potential conflict of interest was reported by the authors.

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APPENDIX

General information for apraxic and phonological (conduction) aphasic individuals.

	Age (years)	Type of accident	Site of lesion	% word correct by Task			Non-lexical Paraphasias		Substitutions and deletions (rates/*N* individual errors)				Simplification rate (rate/ sub + del + ins)				Phonetic errors	
				Rep	Read	Nam	(rates/total err)		Sub		Del		Simpl		Compl		(rates/*N* words)	
				%	%	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%
Apraxic																		
A.M.	52	CVA	Left temporal (cortical, sub-cortical)	**43.7**	**34.5**	**43.7**	929	**86.5**	939	**89.1**	57	**5.4**	806	**76.5**	75	**7.1**	196	**25.4**
A.P.	60	CVA	Left basal-nucleus	**75.9**	**80.2**	**64.4**	438	**91.1**	308	**70.5**	100	**22.9**	248	**56.8**	106	**24.3**	96	**12.4**
A.V.	64	CVA	Left front-parietal	**48.0**	**27.6**	**15.8**	753	**77.5**	340	**46.3**	319	**43.5**	325	**44.3**	275	**37.5**	122	**21.3**
D.C.	55	CVA	Left temp-front-parietal	**6.5**	**35.2**	**2.9**	1324	**85.7**	803	**77.1**	136	**13.1**	442	**42.5**	254	**24.4**	101	**13.7**
D.G.	30	CVA	Left temporal (cortical-subcortical)	**51.6**	**61.4**	**42.7**	797	**89.1**	486	**58.9**	129	**15.6**	404	**49.0**	216	**26.2**	103	**13.3**
E.M.	59	CVA	Left temp-parietal	**8.9**	—	—	662	**94.4**	549	**67.0**	160	**19.5**	532	**65.0**	116	**14.2**	64	**16.4**
G.C.	55	CVA	Left lenticularis capsule	**63.1**	**55.6**	**30.6**	642	**90.7**	573	**77.5**	124	**16.8**	557	**75.4**	54	**7.3**	109	**14.1**
M.I.	54	CVA	Left temp-parietal	**58.3**	**28.2**	**35.4**	748	**72.1**	576	**70.5**	154	**18.8**	449	**55.0**	139	**17.0**	164	**24.0**
O.B.	73	CVA	Left temp-front-parietal	**51.6**	**46.1**	**35.2**	788	**87.1**	427	**62.4**	126	**18.4**	257	**37.6**	173	**25.3**	124	**16.4**
P.V.	50	CVA	Left broad area of median artery	**43.8**	**50.7**	**39.9**	697	**73.3**	457	**70.6**	89	**13.8**	257	**39.7**	150	**23.2**	129	**17.2**
S.R.	68	CVA	Left front-temp-parietal (cortical, sub-cortical)	**74.3**	**66.9**	**57.1**	481	**86.7**	237	**49.8**	132	**27.7**	234	**49.2**	126	**26.5**	79	**10.2**
Total				**47.8**	**48.7**	**35.3**	8259	**84.1**	5695	**68.8**	1526	**18.4**	4511	**54.5**	1684	**20.4**	1287	**16.6**
Phonological																		
A.C.	71	Cva	Left silvian cisterna	**76.9**	**82.7**	**61.7**	297	**71.1**	213	**72.7**	38	**13.0**	94	**32.1**	95	**32.4**	7	**1.1**
D.S.	23	Head injury	Left temp-front-parietal	**70.2**	**85.6**	**60.5**	354	**82.3**	198	**70.5**	36	**12.8**	106	**37.7**	80	**28.5**	24	**3.3**
G.A.	65	CVA	left front-temporal	**96.2**	**63.9**	**63.9**	259	**66.8**	191	**81.3**	13	**5.5**	49	**20.9**	48	**20.4**	0	**0.0**
G.M.	65	CVA	Right parietal	**83.4**	**60.9**	**64.1**	392	**69.1**	267	**74.8**	38	**10.6**	84	**23.5**	104	**29.1**	14	**1.8**
L.B.	72	CVA	Left temp-front-parietal	**89.7**	**89.7**	**80.3**	174	**84.5**	106	**63.5**	45	**26.9**	49	**29.3**	64	**38.3**	35	**4.5**
M.C.	71	CVA	Left parietal	**22.5**	**52.3**	**31.6**	965	**80.1**	631	**65.7**	98	**10.2**	276	**28.8**	298	**31.0**	21	**3.9**
M.P.	66	CVA	Left temp-parietal	**74.1**	**84.9**	**79.6**	223	**57.9**	139	**73.9**	27	**14.4**	47	**25.0**	54	**28.7**	4	**0.5**
R.M.	70	CVA	Left parietal	**83.1**	**89.9**	**55.1**	245	**72.1**	137	**69.2**	26	**13.1**	72	**36.4**	73	**36.9**	18	**2.4**
T.C.	32	CVA	Left subarcno. peri-silvian	**71.3**	**77.9**	**48.1**	363	**67.5**	231	**80.8**	24	**8.4**	57	**19.9**	69	**24.1**	11	**1.4**
V.S.	60	CVA	Left parieto-occipital	**25.8**	**32.9**	**35.7**	1028	**89.5**	532	**67.0**	73	**9.2**	146	**18.4**	186	**23.4**	38	**4.9**
Total				**69.3**	**73.8**	**57.2**	4300	**76.4**	2645	**70.4**	418	**11.1**	980	**26.1**	1071	**28.5**	172	**2.4**

Note: Rep = repetition; read = reading; nam = naming; sub = substitutions; del = deletions; CVA = cerebrovascular accident; simp=simplifications; comp=complications.