Description, explanation, and prediction in the study of phonological deficits in aphasia

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Disordered speech in aphasia has been viewed as a problem for linguistic analysis for over a hundred years (Freud, 1891/1953). As theoretical linguistics has evolved throughout the twentieth century, studies of aphasic language have followed, incorporating theoretical advances and attaining greater and greater levels of descriptive and explanatory adequacy. As theories of phonology have developed, the study of neurolinguistics has profited from the application of those developments to the study of phonological deficits in aphasia.

The theoretical notions of representations and rules have provided useful concepts and vocabulary for the *description* of error patterns observed in aphasic speech (Blumstein, 1973). With the advent of autosegmental phonology, richer theoretical models of segmental representation have been elaborated which have allowed researchers to develop *explanations* for why some error types are observed in aphasic speech with greater frequency or to the exclusion of other types (Béland, Paradis and Blois, 1993). To date, however, theories of phonological deficits in aphasia have failed to achieve any level of *predictive* adequacy.

After reviewing two landmarks from past models in linguistics that have served as underpinnings to theories of phonological deficits in aphasia (SPE distinctive features and autosegmental phonology), this paper will highlight a major limitation of these approaches: all previous theoretical approaches to the study of phonemic paraphasias – including these two – fail to account for the variable performance typically observed in the production of phonemic paraphasias. We will then turn to a very recent evolution in theoretical phonology, Optimality Theory, for an approach that avoids this limitation. Within this theoretical framework, the Inoperative Constraint Hypothesis will be introduced, illustrating how this approach not only provides an explanation for the facts that prove to be a limitation for previous approaches but goes beyond these models in its theoretical adequacy by providing predictive power that motivates clear, testable hypotheses for future research.

In the framework of SPE (Chomsky and Halle, 1968), grammatical knowledge is conceptualized as «rule-governed behavior» which can be characterized in theoretical terms by writing linear rules. Within this approach phonological phenomena in a language follow from the application of such rules to specified phonological targets in particular phonological environments. Phonological paraphasias in aphasic speech can be described in the same terms. Either rules of the grammar which would normally be triggered are, for reasons of the neurological impairment, not applied. Alternatively, rules that are not normally part of the grammar may appear to be applied.

This framework has made its greatest contribution to the study of phonemic paraphasias in providing researchers with the tools to develop a very precise description of phonological impairments. The model has approached explanatory adequacy insofar as the theoretical notion of features appears to be neurolinguistically relevant. Some researchers have found that errors that differ from their targets by a single feature (1a) occur more frequently than errors that differ by two or more (1b) (Blumstein, 1973, 1981), though other researchers have suggested that this is not true for all aphasics (Buckingham, 1992).

(1)	a.	***doll***	/dal/ → [tal]	[+voice] → [–voice]
		teams	/timz/ → [kimz]	[–back] → [+back]
	b.	***doll***	/dal/ → [kal]	$\begin{bmatrix}\text{+voice}\\ \text{–back}\end{bmatrix} \rightarrow \begin{bmatrix}\text{–voice}\\ \text{+back}\end{bmatrix}$

With the advent of autosegmental phonology (Goldsmith, 1979), the theoretical understanding of grammatical knowledge is no longer one of a complex rule component that applies to simple bundles of features. Rather, a greatly reduced component of phonological rules is applied to considerably enhanced segmental representations. Within this framework phonological phenomena are seen to follow from the nature of richly articulated feature geometries (Clements, 1985; Sagey, 1986). In this context, phonemic paraphasias can be described in terms of the misapplication of the general phonological rules or in terms of their proper application over defective representations. Furthermore, this multi-linear approach provides an explanation for why certain sets of features (e.g., place features) tend to be affected as a group in phonological deficits (Blumstein, 1981) as well as why certain segment types (e.g., coronal) tend to be disproportionately vulnerable to impairment (Béland, Paradis and Blois, 1993).

A major limitation to both of these approaches, as well as all theoretical approaches to phonological deficits in aphasia to date, is the variable performance that is typically observed among aphasics. Both variability across individuals and variability in the performance of a single individual. The errors produced by one aphasic are never guaranteed to occur in the output of another aphasic. Moreover, a single individual may produce a systematic error upon one attempt at a target only to successfully produce the same target upon a subsequent trial. In addition, when individuals make successive approximations in an effort to achieve an accurate output (i.e., *conduite d'approche*), they demonstrate sensitivity to the errors in their own productions and appear to be capable of modifying the application of their impaired phonologies. Such variability has led some researchers to resort to a characterization of aphasia as a deficit that «momentarily» impairs the operation of grammatical mechanisms (Béland, Paradis, and Blois, 1993:??). Consequently, the linguistic approach to the study of phonemic paraphasias has been reduced to descriptions of the error types that are observed and explanations of tendencies (i.e., the frequency distributions of different error types).

A recent evolution in theoretical phonology (actually a full theory of grammar in general), which has been referred to as «THE linguistic theory of the 1990's» (Archangeli, 1997: 1), is Optimality Theory (Prince and Smolensky, 1993). As a theory of grammar that maps underlying forms onto surface forms by way of as universal set of constraints, Optimality Theory (OT) constitutes a radical shift in the conception of what grammatical knowledge is like. Unlike traditional rule-based models of grammar, OT accounts for phonological phenomena through a process of constraint satisfaction. A component of the grammar generates a set of candidate outputs which are evaluated by an idiosyncratically-ranked universal set of constraints. The effect of this constraint hierarchy is to prevent all but the correct form from being produced.

There are three fundamental properties of constraints within OT. First the constraints are universal. That is, all languages contain the same set of constraints. Second, constraints are surface-violable. In other words, correct outputs nevertheless violate some of the constraints. Third, it is precisely the ranking of the constraints into a strict dominance hierarchy that distinguishes languages from one another. Though all languages contain the same set of constraints, each language ranks that set of constraints differently.

Properties of a particular grammar in OT are typically characterized with the help of a constraint tableau as in (2). Constraints are listed across the top of the tableau in order of their ranking from left to right. The list of possible candidate outputs for a given input appears in the left-hand column. An asterisk (*) indicates a violation of a constraint by a particular candidate. If incurring the violation is fatal (i.e., it prevents a candidate from surfacing as the output), then an exclamation mark (!) is added. The pointing finger (p) indicates the correct, or «optimal», output. Finally, shaded cells indicate constraints that are no longer relevant for determining the optimal candidate.

(2) **Constraint Tableau**

/input/		C_1	C_2	C_3	C_4	C_5	C_6
	candidate 1				*	*!	
	candidate 2	*!					*
	candidate 3			*!			
☞	candidate 4				*		
	candidate 5		*!				*

* = Constraint violation
*! = Fatal violation (candidate no longer considered)
☞ = Optimal candidate (candidate 4)
[shaded] = Constraint not relevant for this candidate

Turning to phonological impairment in aphasia within the context of Optimality Theory, I propose the Inoperative Constraint Hypothesis in (3).

(3) **Inoperative Constraint Hypothesis** (ICH)

Aphasia renders phonological constraints inoperative from the bottom of the constraint hierarchy up to a level of the hierarchy determined by the severity of the impairment

According to this hypothesis, aphasia results in a subset of the ranked constraints being rendered inoperative. In milder cases of aphasia, only more lowly ranked constraints are rendered inoperative, whereas more severe cases impede the operation of more highly ranked constraints in addition to those lowly ranked constraints. In formal terms, the non-operative status of one constraint implies the non-operative status of all constraints ranked below that constraint. Therefore, the severity of aphasia correlates with the proportion of the constraint hierarchy that is rendered inoperative. In addition, it is the hierarchical organization of constraints, rather than the internal content of the constraints themselves, that determines the susceptibility of a particular constraint to impairment in aphasia, with more lowly ranked constraints being more vulnerable than constraints ranked more highly.

The constraint tableaux in (4) illustrate the effects of the ICH under impairments of different degrees of severity.

(4) **Inoperative constraints in aphasia of different degrees of severity**

a. *Mildly impaired grammar*

/input/		C_1	C_2	C_3	C_4	C_5	C_6
☞	candidate 1				*	*!	
	candidate 2	*!					*
	candidate 3			*!			
☞	candidate 4				*		
	candidate 5		*!				*

b. *Moderately impaired grammar*

/input/		C_1	C_2	C_3	C_4	C_5	C_6
☞	candidate 1				*	*!	
	candidate 2	*!					*
☞	candidate 3			*!			
☞	candidate 4				*		
	candidate 5		*!				*

c. *Severely impaired grammar*

/input/		C_1	C_2	C_3	C_4	C_5	C_6
☞	candidate 1				*	*!	
	candidate 2	*!					*
☞	candidate 3			*!			
☞	candidate 4				*		
☞	candidate 5		*!				*

A mild case of aphasia (4a) renders constraints inoperative from the bottom of the hierarchy. With constraints C_5 and C_6 inoperative, the impaired grammar has no way of preventing candidate 1 from surfacing as a possible output. This results in grammatical «optionality». In other words, the grammar permits both candidate 4 and candidate 1 as possible outputs for this input. A moderate impairment (4b) will similarly render constraints inoperative from the bottom of the hierarchy, though a greater proportion of the constraint hierarchy is affected. In this case, the constraints that would normally prevent candidate 1 and candidate 3 from surfacing as outputs are no longer operative, thus increasing the set of output options to three. In a severe case of aphasia (4c), an even greater portion of the constraint hierarchy is rendered inoperative, resulting in an even larger set of «optimal» (optional) outputs which become possible output forms for the impaired phonology.

Rendering a constraint, or a set of constraints, inoperative effectively increases the set of optimal output candidates from a pre-morbid set of one, unique, optimal surface form to a set of greater than one. This results in an impaired grammatical system that allows for a range of possible outputs that includes the pre-morbidly optimal candidate in addition to forms traditionally described as errors. This characterization of impaired phonology accounts for the consistent observation among individuals who produce paraphasias upon one attempt at a target yet are able to successfully produce the target upon a subsequent trial. The ICH makes the following implicational prediction. If an error indicative of a particular constraint's inoperative status is present in the output of an individual's aphasic speech, then errors resulting from the inoperative status of all constraints more lowly ranked in the hierarchy will also be present.

The Inoperative Constraint Hypothesis, couched within Optimality Theory, provides an explanation for the variability in performance frequently observed in the production of phonemic paraphasias. Moreover, the ICH goes beyond previous theories of phonological deficits in aphasia insofar as it makes explicit predictions about the range of phonemic paraphasias an individual will produce, thus providing clear, testable hypotheses for future research.

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