Available online at www.sciencedirect.com
ScienceDirect
Lingua
Lingua xxx (2008) xxx–xxx
www.elsevier.com/locate/lingua

Minimizing and optimizing structure in phonology: Evidence from aphasia

Adam Buchwald *

New York University, Department of Speech-Language Pathology & Audiology, 665 Broadway, Suite 900, New York, NY 10012, United States

Received 27 June 2007; received in revised form 31 October 2007; accepted 12 November 2007

Abstract

At the phonological level, languages differ with respect to the amount of structural complexity they permit. However, even though a language may permit complex structures (e.g., onset consonant clusters), the grammar still differentiates the complex structures from less marked structures (e.g., singleton onset consonants) which are also permitted in the language. This paper explores the performance of VBR, an aphasic English speaker, whose deficit has affected her grammar by disallowing previously permitted marked forms, and thus minimizing structural complexity. It is shown that her impairment affects a level of phonological processing at which output forms are computed, and her grammar may be captured by an Optimality Theory account that differs minimally from that of an unimpaired English speaker. Through a thorough survey of VBR's performance, it is shown that the phonological processing system is constrained by factors that favor structures with minimal complexity.

Keywords: Aphasia; Phonology; Repair; Epenthesis; Optimal structure

1. Introduction

Jakobson (1941/1968) famously argued that the same principles of phonological complexity govern the cross-linguistic distribution of sounds, the acquisition of sounds, and the loss of phonological abilities in aphasia. This claim forms part of the foundation of *markedness*, a central concept in generative linguistics that provides a vehicle for expressing linguistic complexity (also see Trubetzkoy, 1939/1969; Chomsky and Halle, 1968, Chapter 9; Greenberg, 1978; Paradis and Prunet, 1991; Prince and Smolensky, 1993/2004). Certain linguistic structures (e.g., onset consonant clusters, as in *cl*one) are argued to be marked relative to other linguistic structures (e.g., singleton consonant onsets, as in *c*one), with unmarked structures more common cross-linguistically, less restricted within a language, and argued to be acquired and processed with greater speed and accuracy than their marked counterparts (cf. Edwards and Beckman, 2008). This paper presents experimental evidence indicating that markedness constrains the representation and processing of phonological information. To this end, we will examine the performance of an aphasic native English

* Tel.: +1 212 998 5260; fax: +1 212 995 4356.
E-mail address: buchwald@nyu.edu.

0024-3841/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.lingua.2007.11.015

Please cite this article in press as: Buchwald, A., Minimizing and optimizing structure in phonology: Evidence from aphasia. J. Linguistics (2008), doi:10.1016/j.lingua.2007.11.015

speaker, VBR, which provides support for the claim that markedness – and the minimization of complex linguistic structure – plays an active role in phonological processing and can serve to constrain linguistic output in cases of acquired language impairment.

VBR's spoken production contains a variety of systematic errors, and a critical pattern discussed here is her treatment of word-initial consonant clusters. In particular, VBR typically ''repairs'' these sequences by inserting a vowel in consonant clusters (e.g., *clone* → [kəlon]), thereby removing the complex structure. Using this pattern as a point of departure, we will view evidence from a variety of experimental production tasks that support the assertion that VBR's phonological grammar – active in spoken language production – repairs certain types of marked structure in English.

After reviewing phonological and phonetic evidence from a variety of patterns of VBR's performance to address the nature of her impairment, we will see how her performance may be accounted for in Optimality Theory (OT; Prince and Smolensky, 1993/2004). The notion of markedness as a central determinant of linguistic well-formedness is formalized in OT, which represents phonological grammar as the interplay between constraints minimizing markedness in output forms and constraints promoting faithfulness to a linguistic input. It is argued that an account in this framework that captures VBR's performance – as well as the grammar of unimpaired English – is tantamount to evidence for Jakobson's assertion that the same principles of phonological complexity govern cross-linguistic sound patterns as well as the sound patterns in individuals who suffer from language loss.

The remainder of this paper is structured to advance these claims. Section 2 discusses how evidence from aphasic speakers can be brought to bear on phonological issues, and then presents the case of VBR, who is shown to have an acquired language impairment which systematically alters her spoken productions. Section 3 examines VBR's repairs of consonant clusters and other related sound structure patterns in English, and it is shown that structural differences among similar sound sequences are associated with different repairs, and that the nature of the repair is in accordance with the structural properties of the sequences. Section 4 sketches an OT analysis of the impaired grammar of VBR contrasted with the grammar of an unimpaired English speaker, and considers the larger relationship between markedness and deficits that arise due to brain damage, and it is concluded that patterns seen in language loss are constrained by the same principles as those which constrain cross-linguistic patterns.

2. Aphasia and phonology

In this paper, data from an aphasic speaker are used to provide support for the claim that markedness actively constrains performance in the case of language loss. If Jakobson's (1941/1968) assertion provided above is correct, this would entail that patterns of performance from aphasic speakers can provide insight into the nature of phonological knowledge. This notion dovetails with the key assumptions and goals of cognitive neuropsychology, which focuses on the performance of individuals with acquired (or developmental) impairments on a variety of cognitive tasks (not limited to language); as argued by Caramazza (1986) among others, one main objective of cognitive neuropsychology is to explicitly articulate the nature of mental representations and processes that underlie cognitive abilities such as spoken language production (see Rapp and Goldrick, 2006 for a review of the contribution of cognitive neuropsychology research to our understanding of spoken production). Data from impaired populations has been useful in furthering our understanding of linguistic knowledge and processing (e.g., Béland et al., 1990; Blumstein, 1973; Blumstein et al., 1980; Buckingham, 1986; Dogil and Mayer, 1998; Goldrick and Rapp, 2007; Romani and Calabrese, 1998; Romani et al., 2002). The present in-depth analysis of VBR follows in this tradition, and is performed to provide further insight into the phonological processing system as well as phonological grammar. The outcome of these empirical investigations suggests that markedness – by minimizing complexity in phonological representations – is an active constraint on phonological processing.

2.1. Using cognitive neuropsychological data

One critical component of the single-case study approach is to ensure that the errors under examination inform us about a relevant portion of spoken production processing. For example, if an individual has difficulty in lexical access, or if damage affects the long-term storage of lexical representations, the pattern of performance that we observe may be informative about those systems, but not necessarily phonological grammar. Similarly, if brain-damage leads to a motor deficit that affects articulatory implementation, it may not make sense to claim that we can learn about phonological grammar from the pattern of performance that we observe. Thus, it is critical that an investigation of this nature include detailed analyses aimed at identifying the locus of the deficit. In the remainder of this section, three possible loci of impairment are considered, as well as possible means for determining which level is impaired.

2.1.1. Phonological processing and levels of impairment

In a recent paper contrasting two aphasic individuals with different levels of impairment, Goldrick and Rapp (2007) argued that the tasks of picture naming and repetition may be used to address the issue of where errors of aphasic speakers arise in the spoken production system. In particular, they focused on the cognitive processes that must be active in performing these tasks. In a picture naming task, an individual is required to access the picture name from their lexicon (after identifying the picture) prior to producing spoken output. In contrast, repetition (and particularly nonword repetition) does not necessarily require accessing a lexical item in the lexicon as the phonological form is presented as part of the task. Both picture naming and repetition require phonological processing that generates detailed phonetic representations from which motor plans can be constructed.

The pattern of performance on these two tasks can help identify the level of an individual's deficit. If phonological errors are made in picture naming but not repetition, this would indicate impairment to the access or long-term storage of phonological representations in the lexicon (called *lexical phonological processing*). Lexical phonological processing is the portion of the processing system that is concerned with relatively arbitrary mappings from meaning to sound. In contrast, a pattern in which phonological errors are quantitatively and qualitatively similar in picture naming and repetition indicates a locus of impairment central to each task. Goldrick and Rapp refer to this phonological component of as *post-lexical phonological processing*. Post-lexical phonological processing is the portion of the phonological processing system that is responsible for the relatively predictable mapping from a somewhat sparse representation (e.g., /kæt/) to a more detailed representation (e.g., [k^{h}æt]) based on language-particular regularities, and may be thought of as the grammar portion of phonological processing (see Buchwald, 2005 for a more in-depth discussion of this point).

2.1.2. Motor impairment and phonological processing

It is critical to note that there are potentially several post-lexical levels of cognitive processing that are involved in spoken language production. As noted above, errors of motor implementation (e.g., dysarthrias) are post-lexical, but it would be inappropriate to consider the errors that arise in these cases as being created by the grammar. However, an individual whose errors are driven by an articulatory impairment is likely to show the same qualitative and quantitative performance on all production tasks. Thus, the performance of individuals on tasks of picture naming and repetition may not be sufficient to differentiate a motor impairment affecting articulation from a post-lexical phonological processing impairment. This issue will be addressed in section 2.3.2.

2.2. VBR: Case history

VBR is a 58-year-old right-handed monolingual American English-speaking woman who suffered a cerebral-vascular accident (CVA) six years prior to the onset of the current investigation. MRI scans reveal a large left hemisphere fronto-parietal infarct involving posterior frontal lobe, including Broca's area, pre- and post-central gyri and the supramarginal gyrus. VBR has a right hemi-paresis as a result of the CVA; she occasionally uses support to walk, and has limited use of her right arm below the elbow. The CVA also induced strabismus, for which she wears corrective lenses. Prior to her CVA, VBR was the president of a small company. VBR's language production skills are severely impaired as a result of the CVA, particularly her spoken output.

The evidence discussed below includes data from spoken repetition tasks with VBR. Because this paper focuses on VBR's spoken production output, it is critical to determine whether errors that are made in repetition tasks could come from a deficit in perception or word recognition. Two tests were administered to assess VBR's perception: the Psycholinguistic Assessments of Language Processing in Aphasia (PALPA; Kay et al., 1992) word same-different discrimination task, and the PALPA nonword same-different discrimination task. In these tasks, the experimenter reads two words (or two nonwords) approximately 1 s apart, and the subject responds whether the two words or nonwords are the same (word: house–house; nonword: zog–zog) or different (word: house–mouse; nonword: zog–zeg). VBR's performance was nearly flawless on both the word task (71/72; PALPA-reported control subjects = 70.4/72) and the nonword task (71/72; no norms are provided), indicating that an impairment in repetition is unlikely to be due to a problem in parsing auditorily presented linguistic input.

In addition, to assess VBR's lexical access in spoken word recognition tasks, she was administered the auditory lexical decision component of the PALPA (Kay et al., 1992). In this task, the experimenter reads a stimulus form (e.g., [tənǽko]), and the participant identifies the stimulus as either a word or a nonword. VBR's performance on auditory lexical decision was within the normal range for both nonwords (78/80 correct; control subjects = 76) and words (79/80; control subjects = 79.4). The results of these tests suggest that her ability to perceive and correctly identify spoken words and nonwords remains intact, and performance problems in repetition tasks are not likely to be due to errors in identifying the target word.

2.3. Determining the level of impairment

This section presents the results of tests administered to VBR that allow us to determine the level of her impairment in the cognitive system responsible for spoken language production.

2.3.1. Lexical and post-lexical phonological processing

To address the issue of whether VBR's impairment arises at the level of lexical phonological processing or at a post-lexical level (see discussion in section 2.1), her performance on picture naming tasks was compared to her performance on repetition tasks, in which the lexical item is presented to the participant (following Goldrick and Rapp, 2007). In a series of 33 items presented both as pictures for naming and as words for repetition, VBR performed both qualitatively and quantitatively similarly on both tasks. In particular, her performance in the picture naming task (64% words correct; 85% phonemes correct) matched her performance in word repetition (67% words correct; 85% phonemes correct). The errors were of a similar nature in each task, marked primarily by single segment substitutions (e.g., *gun* → [kʌn]), deletions (e.g., *shoulder* → [ʃodʒ˞]) and insertions (e.g., *glass* → [gəlæs]). The strong similarity in both the quantity and quality of errors in picture naming and word repetition tasks suggests that VBR's phonological errors do not arise at the level of lexical phonological processing.

This conclusion is supported by VBR's performance on 33 nonwords presented for repetition. The nonwords were assembled with the same segments (and syllables, as much as possible) as the 33 words in the list discussed above, and VBR correctly repeated 20/33 nonwords (61%). In terms of phoneme accuracy, VBR's repetition performance with these nonwords is statistically indistinguishable from those reported above (82% phonemes correct, $\chi^2 = 0.69$, *ns*). These findings demonstrate that VBR's deficit impairs both naming and repetition tasks, yielding similar levels of impaired performance on each task, which suggests that her deficit affects a post-lexical level of the cognitive system responsible for spoken production.

2.3.2. Ultrasound investigation of VBR's vowel insertion

As mentioned above, one widespread pattern in VBR's productions is schwa epenthesis in obstruent-sonorant word-initial clusters (e.g., *clone* → [kəlon]). This pattern may arise due to impairment to post-lexical phonological processing – the grammar portion of the spoken production system (see section 2.1.1) – in which the marked consonant cluster is avoided by the epenthesis repair. Alternatively, it remains possible that a motor problem leading to the mistiming of articulatory gestures could create this repair (see section 2.1.2). If this were the case, it would complicate the use of this pattern as evidence regarding the system of phonological grammar (cf. Davidson, 2003, 2006). This issue was addressed by Buchwald et al. (2007) who reported an ultrasound imaging study designed to address the locus of VBR's schwa insertion errors, and their findings are briefly summarized here (see Buchwald et al., 2007, for a fuller description of this study).

VBR produced CC-initial words (e.g., *cl*one) as well as control words with the same initial sequence containing a schwa between the two consonants (e.g., *colo*gne, [kəlon]). During these productions, her tongue movements were recorded with ultrasound imaging, and an acoustic record was collected as well. Recording the tongue with ultrasound imaging allows us to examine the tongue contours at different points in articulation (Stone, 1991). In one line of research investigating consonant cluster production with ultrasound, Davidson (2003, 2005; also see Davidson and Stone, 2004) examined the tongue contours in English speakers who produced certain non-native clusters (e.g., [zgomu]) with a vocalic insertion between the two consonants (e.g., [zəgomu]). Davidson reported that the sequence and timing of tongue contours more closely approximated productions of the cluster [sk] (as in *scum*) than production of the sequence [sək] (as in *succumb*). These data led her to conclude that these speakers are not inserting a new articulatory gesture for schwa into their target production; rather, they are mistiming the articulatory gestures associated with the consonant cluster.

The logic behind the Buchwald et al. (2007) study mirrored that of Davidson's work. Ultrasound imaging was used to compare VBR's productions of 22 words with consonant clusters (e.g., *clone* produced as [kəlon]) with her production of matched words containing a schwa between the consonants (e.g., *cologne*), with each stimulus word produced four times in succession. Data from a control speaker (an unimpaired speaker of American English with no awareness of the study) indicated that the ultrasound protocol employed by Buchwald et al. was sensitive enough to detect the difference between these two sequences, as schwa was detectable between the two consonants in CəC-initial words (e.g., *cologne*) but not in CC-initial words (e.g., *clone*).

In contrast to the unimpaired speaker, VBR's data from both the ultrasound imaging analysis and acoustic analyses provided clear and consistent evidence indicating that the production of inserted schwa (e.g., *clone* → [kəlon]) was indistinguishable from the production of lexical schwa in the CəC-initial words (e.g., *cologne*). The tongue contours associated with each schwa type (inserted and lexical) were extracted and these were compared to one another, and to the adjacent articulations. Contrary to what one may predict in consonantal mistiming, inserted schwas and lexical schwas were statistically indistinguishable (see Fig. 1), and inserted schwas were more similar to lexical schwas than to the adjacent consonantal gestures. Further, when the inserted schwa tongue contours from different repetitions of a target word were compared to one another (e.g., *cologne* repetition 1 compared to repetitions 2–4), and the lexical schwa tongue contours were compared to one another (*clone* repetition 1 vs. 2–4) the resulting within-category differences were statistically indistinguishable from the differences between inserted schwa and lexical schwa, indicating that these two sets of tongue contours come from the same statistical population.

Second, the sequence of articulations from the first consonant through the schwa to the second consonant (e.g., the [k], [ə], [l] of [kəlon]) were indistinguishable for VBR's production of *clone* and *cologne*, a pattern which was not true for an unimpaired control speaker (and was not true in data reported by Davidson, 2005). Third, the acoustic record revealed no differences between the two schwa types in duration, variability, or co-articulation with the following vowel (e.g., the [o] in [kəlon]); durational differences were reported in Davidson, 2005).

These lines of evidence suggest that the inserted vowel in VBR's consonant cluster productions gives rise to the same articulatory and acoustic event as is seen in her production of lexical schwa. That is, the error productions with an inserted vowel are not distinguishable from the production of words with an articulatory target for schwa. This result suggests that VBR is repairing the consonant cluster with schwa epenthesis, indicating that this is unlikely to result from impairment to motor coordination, and instead arises due to impairment to post-lexical phonological processing.

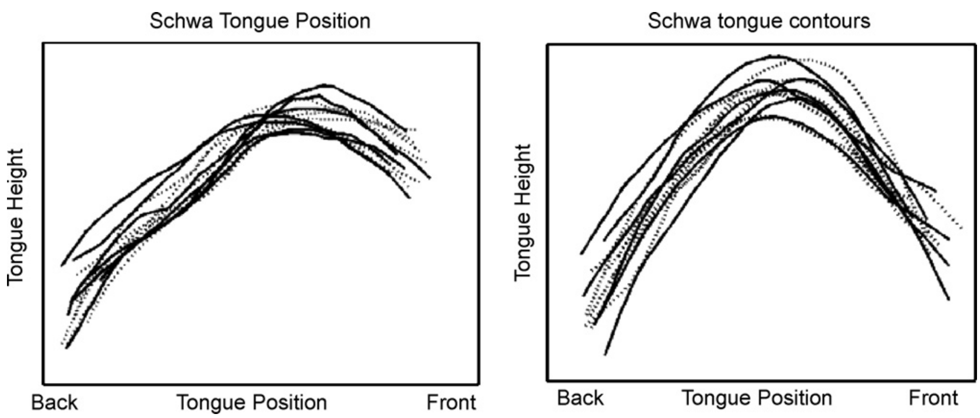


Fig. 1. VBR's inserted vowel (solid lines) and lexical schwa (dotted lines) tongue contours from ultrasound imaging. The left panel depicts inserted and lexical schwa contours for tokens with labial C_1 and /i/ as stressed the vowel, and the right panel depicts contours for tokens with velar C_1 and /o/ as stressed vowel. These pictures demonstrate that there are not systematic differences between the two schwa contours. (Reprinted from Buchwald et al., 2007.)

2.4. Summary

This section reviewed data from VBR's impaired spoken output. The results indicated that VBR has an acquired language impairment which has led to a post-lexical phonological processing deficit. The error patterns observed in her performance are attributable neither to a deficit in storing or accessing lexical representations (lexical phonological processing), nor to a deficit affecting the motor production system required for speech articulation. The post-lexical phonological processing system has elsewhere been identified as the system responsible for the systematic (i.e., grammatical) mappings in phonological processing (Buchwald, 2005). The next section explores an additional pattern in VBR's productions and its relationship to the issue of markedness as a defining property of phonological processing.

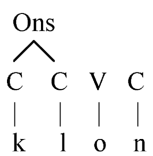
3. Representation-specific repairs

In this section, VBR's production repairs are shown to vary for similar surface forms that have different phonological representations. The data addressed in this section come from VBR's overall patterns of production of words containing: onset consonant clusters; consonant-/ju/-initial words; and affricates. VBR's productions of these sequences indicate that the production errors in her speech are based on the particular sound structure representation of the sequence she is producing, and it is argued that this is indicative of the phonological grammar playing a critical role in the determination of the "repaired" output. The section concludes with a summary of the relevant data discussed here.

3.1. Word-initial obstruent-liquid clusters

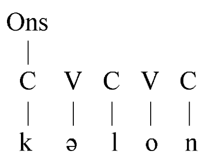
Heretofore, the discussion of VBR's errors has focused on her schwa epenthesis in obstruent-liquid onset clusters (e.g., *clone* → [kəlon]). The critical factor with respect to these errors is that they involve the reduction of complexity of the target structure. The structural description of a typical word-initial obstruent-liquid cluster is represented in (1):

(1) *Representation of obstruent-liquid onset*



As can be seen in (1), words with obstruent-liquid onsets have complex onsets, with two consonants associated with the onset. In attempting to produce these sequences, VBR uses a systematic repair process to minimize the complex structure: schwa epenthesis. Out of 225 words VBR produced with complex obstruent-liquid onsets, she produced 155 (69%) with schwa epenthesis between the two consonants (e.g., [kəlon]).[1] The structural description of these forms is depicted in (2):

(2) *Representation of VBR's schwa epenthesis repair*



VBR's repair of word-initial consonant clusters minimizes the structural complexity by removing the consonant cluster. This repair creates an initial CV syllable, which represents the most common (i.e., least marked) syllable cross-

[1] The presence or absence of schwa insertion was assessed both auditorily and acoustically. The auditory evaluations were made by at least two trained listeners, and were checked against the acoustic record. These data include, but are not limited to, the productions reported in Buchwald et al. (2007).

linguistically (Blevins, 1995). Thus, although schwa is being inserted into the target form, this repair minimizes complexity relative to a consonant cluster, and thus results in a less marked output.

3.2. *Word-initial consonant-glide-vowel sequences*

The remaining obstruent-sonorant onset sequences discussed here have glides as the second consonant. The distinction between English syllables beginning with C/j/V sequences (e.g., *cute* [kjut]; *music* [mjuzɪk]) and those beginning with C/w/V (e.g., *queen* [kwin]; *quote* [kwot]) has been a topic of active phonological inquiry for quite some time (Chomsky and Halle, 1968; Borowsky, 1984; Halle and Mohanan, 1985; Davis and Hammond, 1995; Barlow, 2001; Buchwald, 2006). Although each of these sequences surfaces as a consonant-glide-vowel sequence in English words, several differences have been noted with respect to their phonological patterning in English, leading to the claim that these sequences have a different sound structure representation.

3.2.1. *Structural representation of word-initial CGV sequences*

Davis and Hammond (1995) noted an asymmetry in the distribution of vowels in tautosyllabic consonant-glide-vowel sequences in English. When the glide is /w/, there are few restrictions on the identity of the following vowel (e.g., *queen*, *quote*, *quack*, *quaff*). This type of phonotactic distribution suggests that there is no constituency relationship between /w/ and the following vowel, and that the /w/ forms part of an onset cluster with the preceding obstruent, as shown in (3a). In contrast, when /j/ follows a tautosyllabic consonant, /u/ is the only vowel that follows (e.g., *cute*, *[kjit], *[kjot], *[kjæt], *[kjɑt]). Davis and Hammond argue that this phonotactic restriction suggests a constituency relationship between /j/ and /u/, as depicted in (3b).[2]

(3) a. *Representation of [Cw] as cluster* b. *Representation of [j͡u] as diphthong*

A converging line of evidence discussed by Davis and Hammond (1995) supporting the different structures seen in (3a) and (3b) comes from the range of consonants that surface before these glides. Whereas the first consonant in other onset consonant clusters (e.g., /Cw/; also /Cl/ and /Cr/) is limited to obstruents (*[.mw__], *[.nw__]), /j/ may be preceded by a tautosyllabic /m/, as in *music* ([mjuzɪk]). If /j/ were in the onset, then /mj/ would be the only cluster violating this sonority sequencing restriction. Other potential sonorant onsets (/n/, /l/, /r/) are restricted due to the anti-homorganicity constraint prohibiting a coronal consonant from preceding /ju/. Thus, the sonority-based phonotactic restrictions on consonant-glide-vowel sequences support an account in which /j/ forms a constituent with /u/, and not with the preceding consonant; there are no sonority restrictions on the preceding consonant[3] and strong restrictions on the following vowel.

The representation in (3b) helps to account for the phonotactic restrictions on vowels following apparent consonant-/j/ sequences. Consonant-/j/ sequences do not form consonant clusters, and [j͡u] is the only nuclear diphthong in English with an onglide, so other vowels cannot follow these sequences. Although other vowels follow /j/ when there is no tautosyllabic consonant (e.g., *yellow* [jɛlo]), these sequences are permitted because /j/ is a singleton onset consonant in these forms (see Harris and Kaisse, 1999 for general arguments about this syllabic configuration;

[2] Davis and Hammond (1995), working within a rule-based phonology framework, proposed that this sequence was an underlying diphthong /ɪu/ and a gliding rule is applied prior to its surface appearance. Given the principle of Richness of the Base, for a distinction to be phonologically meaningful it must be a surface distinction. The reader is referred to Buchwald (2006) for a more complete discussion and analysis of these data motivated by this critical OT principle.

[3] Following Steriade (1988) and Davis and Hammond (1995), I assume that constraints on homorganicity may cross the onset-rime boundary whereas constraints on sonority sequencing are limited to pre- or post-nuclear syllabic position. It is also noteworthy that /w/ is another possible onset which does not appear before /ju/. I follow Davis and Hammond (1995:178) in suggesting that there are several possible causes for this that do not affect the generalizations expressed here.

Please cite this article in press as: Buchwald, A., Minimizing and optimizing structure in phonology: Evidence from aphasia. J. Linguistics (2008), doi:10.1016/j.lingua.2007.11.015

and see Buchwald, 2006 for specific arguments with respect to American English). The well-formedness of (3b) also explains the lack of consonantal restrictions on tautosyllabic consonant-/j/ sequences: the initial consonant is a singleton onset, so it is relatively unrestricted with respect to sonority. There is no restriction on the vowel in a form such as (3a), which accounts for the lack of vowel restrictions following consonant-/w/ sequences.

One additional possible analysis of these data considered here is that the C/ju/ sequences are analyzed by English speakers as a single palatalized consonant (C^j) followed by [u]. There exists converging internal and external evidence that are inconsistent with this analysis. First and foremost, if English did have palatalized consonants such as /k^j/, /p^j/, /b^j/, /f^j/, /v^j/, and /m^j/, then it is unlikely that they would be limited to a position only before [u] where they would be contrastive with their non-palatalized counterparts (e.g., *food* ~ *feud*). An account of these sequences containing a palatalized onset consonant would have to capture these distributional data. Further, Davis and Hammond (1995) provided evidence from two language games – Pig Latin and 'The Name Game' that are inconsistent with this account. In each of these games, speakers separate the onset consonant from the palatal glide, suggesting that these are not analyzed as a single segment.

3.2.2. *VBR and consonant-glide-vowel sequences*

If American English speakers analyze consonant-glide-vowel sequences with the sound structure representations depicted in (3a,b), then we would expect these sequences to be treated differently by the phonological grammar. Thus, given VBR's impairment, her production of these two sequences may provide converging evidence for the representations given in (3a,b).

Over the course of testing, VBR produced 23 words with initial consonant-/w/-vowel sequences and 19 words with initial consonant-/j/-vowel sequences. Of the 23 words with C/w/ onsets, VBR produced 19 (82%) with schwa epenthesis between the two consonants, and 2 (9%) with /w/-deletion in the output, with the remaining two produced correctly. In contrast, of the 19 C/j/V-initial words she produced, VBR produced 15 (79%) with /j/ deletion in the output, and the remaining 4 were produced correctly. Crucially, VBR *never* used schwa epenthesis to repair words beginning with C/j/V sequences. Representative productions of these sequences are given in (4):

(4) *Asymmetry in consonant-glide sequence repairs*

a.	Consonant-/w/ sequences	b.	Consonant-/j/ sequences
	queen → [kəwin]		*cute* → [kut]
	quote → [kəwot]		*music* → [musɪk]

The distinction between the repairs of these similar sequences can be accounted for based on the structural descriptions of these word-initial sequences presented in (3a,b). In particular, the consonant cluster /kw/ is repaired via schwa epenthesis, as is typically done to other obstruent-sonorant clusters in VBR's grammar. In contrast, the initial sequence /kj/ in *cute* is not a consonant cluster, so the grammar does not require its repair via schwa insertion.[4] Nevertheless, forms such as *cute* do contain a structurally complex sequence: a rising diphthong. Thus, the rising diphthong creates the problem for the grammar, and this marked form is repaired via /j/-deletion, which removes the phonological complexity.

This section has argued that the /$\widehat{\text{ju}}$/ sequence is analyzed as a rising diphthong by speakers of American English, and that this provides a context for understanding VBR's production of these sequences. In principle, there is no reason why English CjV sequences cannot be analyzed as a consonant cluster followed by a vowel. Given the claim that VBR's patterns follow the different structural representations, if it were possible to present VBR with a sequence containing a /Cj/ cluster, we would expect to see epenthesis as in (4a) rather than onglide deletion as in (4b). However, the principle of Lexicon Optimization (Prince and Smolensky, 1993/2004: section 9.3) suggests that it may be difficult to present VBR with such a form. Lexicon Optimization is the principle wherein language learners store a single underlying representation for each well-formed output representation, rather than storing all possible input representations that would yield the output representation on the surface. As an adult speaker of American English, we

[4] Barlow (2001) argued that some speakers of English may analyze forms beginning with C/j/V as containing a rising diphthong (as in 1b) whereas other speakers may analyze these forms as containing an onset consonant cluster. Thus, VBR's behavior is consistent with an individual who analyzes those words as containing a rising diphthong, and may not apply for all speakers of American English.

Please cite this article in press as: Buchwald, A., Minimizing and optimizing structure in phonology: Evidence from aphasia. J. Linguistics (2008), doi:10.1016/j.lingua.2007.11.015

may assume that VBR's lexicon has been optimized according to this principle. Thus, VBR's lexical representation of words that surface in English with a rising diphthong [j͡u] (e.g., *cute*) also contain a rising diphthong.

One possible means of testing this idea is to give VBR nonwords containing C/j/V onset sequences. However, nonwords such as [kjup] are not an ideal test of the Lexicon Optimization claim, as it is unknown whether speakers identify such forms by analogy to the forms of the native language (in which case, VBR would represent that form as /kj͡up/). A more appropriate test is to present VBR with forms such as [kjop], in which the representation cannot be parsed as containing a rising diphthong in American English (which does not contain /j͡o/). VBR was presented with 10 nonwords of this form, and repeated the forms with a vowel epenthesized between the [k] and [j] in 8/10 trials (the others were correct). This suggests that VBR can analyze CjV sequences as containing a consonant cluster, and the lack of epenthesis in C/ju/ words is due to these words containing a different structure: a rising diphthong rather than not a consonant cluster.[5] We will return to this issue in section 4.2.

3.3. Affricates

Affricates in English are another possible source of evidence regarding the relationship between structural complexity, articulatory complexity, and phonological grammar. English has both voiceless and voiced palato-alveolar affricates (*chain* [tʃen], *jade* [ʤed]). Affricates are considered articulatorily complex, as the successful production has two places of articulation. Although historically there was debate over the issue of the structural complexity of affricates in English, with one account holding that they are represented as a cluster (as in Greenberg, 1978), and another arguing that they are single phonemes (as argued by several, including Lombardi, 1990; Morelli, 1999; Sagey, 1986), there is now consensus on the latter of these accounts (see Clements and Hume, 1995 for discussion of affricates as complex segments).

Two factors motivated the investigation of VBR's affricate production. First, VBR's data may provide further converging evidence in favor of the single segment account of affricates. If she produces them like other singleton onsets, this would favor the single segment account. In contrast, if affricates are broken up with vowel insertion or are produced less accurately than other singleton onsets, this would suggest that affricates are less well-formed in VBR's grammar than singleton onsets, with the former 'repair' suggesting that they form a consonant cluster. The second purpose of this line of investigation relates to the discussion of identifying the level of VBR's deficit as discussed in section 2.3. If VBR's errors were driven by motor problems, we would expect more errors on articulatorily complex segments such as affricates than we see on other singleton consonants. However, given the conclusion from section 2.3 that VBR's errors arise at a phonological level, there is no basis for a distinction between affricates and other singleton onsets.

VBR was presented with 50 words affricate-initial words in repetition and naming tasks. The data support the claim that affricates are represented as single segments, as never VBR inserted a vowel between the /t/ and /ʃ/ (or /d/ and /ʒ/). She produced the affricate incorrectly on 12% of the tokens (6/50). Three errors were devoicing of /ʤ/, and the remaining three involved substitution of a different segment for the affricate (/s/ twice, /b/ once). The error rate is not statistically different from her error rate on singleton consonants (17/150, 11.3%; $\chi^2 = 0.06$, *ns*).

This evidence is consistent with the claim in the phonology literature that affricates are represented as single segments (Lombardi, 1990; Morelli, 1999; Sagey, 1986; cf. Greenberg, 1978). In addition, this pattern suggests that the phonological grammar does not disprefer affricates to the extent that it disprefers consonant clusters (discussed in section 3.1) or rising diphthongs (discussed in section 3.2). The existence of articulatory complexity is not a sufficient condition for VBR's grammar to require a repair; structural complexity is required, and not present in affricates.

3.4. Summary

This section discussed VBR's productions of three patterns in VBR's performance: tautosyllabic consonant-/j/ sequences, and affricates. The presence and nature of a repair strategy was shown to be tied to particular type of structure that was discussed: consonant clusters are repaired via schwa epenthesis; C/j͡u/ sequences – containing

[5] It is noteworthy that loanwords with similar sequences (e.g., *Kyoto*) are typically produced with vowel epenthesis – and thus an initial CV syllable – by unimpaired speakers of American English.

Table 1
Summary of VBR's production data focusing on systematic repairs

Stimulus sequence	Examples	Repair type	% repaired (total *N*)
C_1-liquid onset	[kl̲on]; [br̲id]	Schwa epenthesis	69% (225)
C_1-/w/ onset	[kw̲in]; [kw̲ot]	Schwa epenthesis	79% (23)
C_1-/j͡u/ onset	[kj͡u̲t]; [mj͡u̲sɪk]	/j/-deletion	88% (19)
C_1-/jV/ onset (nonwords with V ≠ u)	[kjop]; [kjit]	Schwa epenthesis	80% (10)
Affricate onset C	[tʃen]; [ʤed]	Not systematic	12% (50)
Other singleton onset C	[tep]; [den]	Not systematic	11.3% (150)

rising diphthongs – are repaired via onglide deletion; and affricates which are not structurally complex are not repaired by the grammar. These data are summarized in Table 1.[6]

4. Constraint interaction and aphasic repairs

This section explores the idea that the repairs in VBR's spoken productions are determined by her phonological grammar, which represents a modification of the grammar for unimpaired speakers of English. In particular, we will see how the patterns discussed above can be accounted for by an OT grammar with minimal deviation from the grammar of unimpaired English. In OT, cross-linguistic differences are captured by re-ranking a set of universal violable constraints, where each constraint ranking corresponds to a possible grammar. This property of OT has been instrumental in its success, as the set of possible constraint rankings in an OT analysis generates the predicted typology, typically ruling out certain patterns from surfacing in any possible grammar (see Prince and Smolensky, 1993/2004; and Smolensky, 2006 for detailed discussions). This fundamental property of OT permits a unique test of Jakobson's claim, given the following linking hypothesis: *if the aphasic grammar can be shown to be within the set of typological possibilities, then this supports the claim that aphasic grammar is constrained by the same principles as normal grammars* (see Pater and Barlow, 2003 for a similar claim regarding phonological acquisition).[7]

4.1. Complex onsets: consonant clusters

In VBR's acquired language deficit, there are systematic repairs of sound structure sequences. What determines the nature of the repairs that are performed? The two critical repairs discussed here are epenthesis in obstruent-sonorant word-initial onsets (e.g., *clone* → [kəlon]) and deletion of the onglide in rising diphthongs (e.g., *cute* → [kut]); each repair is motivated by the avoidance of complex phonological structure. In the following sections, we will see how the mechanisms of OT can capture these two patterns by assuming the elevation of a family of violable markedness constraints – referred to here as *Complex[8] – that prohibit the existence of complex phonological structure in output forms, thereby minimizing marked structures from appearing in output forms.

This section discusses how OT allows us to capture both English and VBR's grammar by assuming that her deficit has led to the promotion of constraints prohibiting complex structure. For the purposes of this section, the critical constraint from the *Complex family is given in (6).

[6] The data presented in Table 1 reflect the systematic patterns seen in VBR's productions. As noted in the rightmost column, the systematic repair types are not used 100% of the time, yielding variability in the output (which was explored in Buchwald, 2007). The OT account that follows in section 4 treats the systematic repairs in the first three lines of the table as if they are always produced by the grammar. To capture the full pattern of variation within OT would require an account that permits variability in the ranking. Several formal means of expressing this variability have been discussed in the literature (stochastic ranking: Boersma, 1998; Boersma and Hayes, 2001; Zuraw, 2000; floating constraints: Anttila, 1997; Legendre et al., 2004; Davidson and Goldrick, 2003). This type of account is beyond the scope of the present analysis.

[7] It is important to note that this type of investigation is only tenable once it has been established that the production patterns of the aphasic speaker under investigation differs from the native language due to a deficit that impairs the spoken production grammar, as was addressed in section 2.

[8] Prince and Smolensky (1993/2004) use *Complex to refer to the constraint prohibiting onsets from being more than a single segment, a usage followed by Pater and Barlow (2003). Given the need to distinguish between the individual constraint prohibiting onset consonant clusters and the constraint family prohibiting different types of complex structure, the general *Complex is used here to refer to the constraint family, and *ComplexOnset is used to refer to the constraint prohibiting onset consonant clusters.

Please cite this article in press as: Buchwald, A., Minimizing and optimizing structure in phonology: Evidence from aphasia. J. Linguistics (2008), doi:10.1016/j.lingua.2007.11.015

Tableau 1
clone in American English

T1		/klon/	MAX-C	DEP-V	*COMPLEXONS
☞	a.	.klon.			*
	b.	.kon.	*!		
	c.	.kəlon.		*!	

(6) *COMPLEXONSET: Onsets are limited to a single segment (Prince and Smolensky, 1993/2004; Pater and Barlow, 2003)

The constraint in (6) targets consonant clusters (as in *clone*). As is always the case in OT, the particular repairs that are seen are determined by the interaction of these markedness constraints with faithfulness constraints. With respect to the insertion pattern seen in VBR's performance, two faithfulness constraints are relevant, given in (7) and (8):

(7) MAX-C: all input consonants must have a correspondent in the output
(8) DEP-V: all output vowels must have a correspondent in the input

With respect to the analyses that follow, MAX-C prohibits consonant deletion, and DEP-V prohibits vowel insertion. For unimpaired English speakers, these faithfulness constraints outrank *CLUSTER, thereby permitting consonant clusters to surface faithfully, as depicted in Tableau 1.

Tableau 1 provides the basic OT account of ranking that permits onset consonant clusters to surface in English: consonant clusters surface in English because the constraints that require faithfulness to consonant clusters in the input outrank the markedness constraint that mediates against consonant clusters in output forms.

Tableau 1 also reports the ranking among these two faithfulness constraints for English as MAX-C $\gg$ DEP-V (see Kenstowicz, 2006 for this ranking argument; also see Davidson et al., 2004, for a similar demonstration of this ranking). This ranking is illuminating when considering VBR's productions. Tableau 2 depicts VBR's grammar, which differs from the English grammar from Tableau 1 in that *COMPLEXONSET – a constraint in the *COMPLEX family – is promoted and ranked above the faithfulness constraints. As we see, the promotion of *CLUSTER above DEP-V leads to the insertion repair seen in VBR's output forms. The patterns discussed here do not allow us to rank *CLUSTER and MAX-C with respect to one another.

4.2. Complex nuclei: rising diphthongs

This section sketches an analysis of tautosyllabic C/ju/ sequences in American English and in VBR's grammar. Although a full analysis of these sequences is outside of the scope of the present work, we will provide a means for accounting for the basic data discussed in section 3.2 of this paper (the reader is referred to Buchwald, 2006, for an in-depth analysis of this pattern that incorporates additional language-internal regularities). In considering the constraints that determine the optimal output, there are two critical differences in an account of VBR's production of *cute* as [kut] compared to the account in section 4.1. With respect to markedness constraints, we must consider another constraint in the *COMPLEX family, given in (9):

(9) *RISING: No nuclear diphthongs with onglides (Barlow, 1996)

The constraint given in (9) – *RISING (Barlow, 1996) – is a markedness constraint that prohibits diphthongs with onglides. It is critical to note that this constraint prohibits a different type of complex sequence, but it is part of the

Tableau 2
clone in VBR's English

T2		/klon/	*COMPLEXONS	MAX-C	DEP-V
	a.	.klon.	*!		
	b.	.kon.		*!	
☞	c.	.kəlon.			*

Please cite this article in press as: Buchwald, A., Minimizing and optimizing structure in phonology: Evidence from aphasia. J. Linguistics (2008), doi:10.1016/j.lingua.2007.11.015

Tableau 3
cute in English

T3	/kj͡ut/	*Cʲ	Dep-V	Ident-V	*Rising
☞ a.	.kj͡ut.				*
b.	.kut.			*!	
c.	.kə.jut.		*!		
d.	.kʲut.	*!			

Tableau 4
cute in VBR's grammar

T4	/kj͡ut/	*Cʲ	*Rising	Dep-V	Ident-V
a.	.kj͡ut.		*!		
☞ b.	.kut.				*
c.	.kə.jut.			*!	
d.	.kʲut.	*!			

larger family of *Complex constraints that prohibit complex structure from surfacing. The analysis of rising diphthongs requires an additional faithfulness constraint that is violated by a change in vowel identity given in (10), and an additional markedness constraint prohibiting palatalized consonants is given in (11):

(10) Ident-V: An input vowel must have the same identity as its output correspondent
(11) *Cʲ: No palatalized consonants[9]

Tableau 3 depicts the optimization that allows *cute* to surface faithfully in American English. The ranking of the two faithfulness constraints above the markedness constraint that penalizes an output for containing a rising diphthong allows the input form to surface rather than being repaired.

Tableau 4 provides an account of VBR's grammar which indicates why the repair applied to *cute* is deletion of /j/. In short, the *Complex constraint family has been promoted and *Rising now outranks the relevant faithfulness constraints.

The optimizations depicted in Tableaux 3 and 4 have input of /kj͡ut/. As discussed in section 3, the property of lexicon optimization leads an adult speaker such as VBR to store only one input representation that leads to an output such as [kj͡ut]: the input–output pairing that is the most harmonic according to the constraint ranking in the language (which *ceteris paribus* will be the most faithful candidate). Section 3.2.2 addressed the difficulty of presenting VBR with C/ju/-initial words to produce that would not be parsed in this way. It is worth noting that the relative ranking of Dep-V ≫ Ident-V does not affect consonant cluster simplification from Tableau 2, as changing the identity of a vowel (i.e., *clone* → [klun]) does not remove the *ComplexOnset violation (see Buchwald, 2006 for a more detailed discussion).

4.3. Aphasia and minimizing markedness of output forms

A natural question that arises in the discussion of VBR's output repairs is whether there is something about the *Complex constraint family that leads these constraints to be promoted in the case of acquired language deficits.[10] In other words, is it necessary that other aphasic individuals will show similar effects of promoted *Complex

[9] This constraint is given as undominated in the following tableaux as it functions as a constraint on the inventory in English and is thus never violated.
[10] I thank Petra Burkhardt for articulating this issue.

Please cite this article in press as: Buchwald, A., Minimizing and optimizing structure in phonology: Evidence from aphasia. J. Linguistics (2008), doi:10.1016/j.lingua.2007.11.015

constraints? More generally, an important question is whether something about the nature of grammar as defined by OT leads to the promotion (or re-ranking) of any class of constraints in aphasia? The answer developed here is that while VBR's data does help provide evidence for the psychological reality of constraint families, it is not necessary that the *COMPLEX family is the one that is affected (and thus promoted) in cases of aphasia. Nevertheless, some general principles appear to be active in aphasic grammar, and a review of these principles suggests future research directions.

*4.3.1. VBR and *COMPLEX*

The basic analyses set forth in sections 4.1 and 4.2 indicate that the systematic pattern of errors seen in VBR's productions can be accounted for if we assume that two markedness constraints – *COMPLEXONSET and *RISING – are promoted in her grammar relative to the faithfulness constraints that penalize output forms for the presence or absence of segments that do not have a correspondent in the input. As has been noted above, these constraints are part of the same family of markedness constraints that penalize output forms for containing structural complexity. It is worth considering VBR's performance on other complex structures to determine whether there exists additional evidence that this constraint family has been promoted in VBR's grammar.

VBR was asked to produce 68 words with a variety of complex codas. Of these codas, she produced 35 correctly (51%). Unlike her production of onset clusters, VBR's repair strategy in producing codas was highly variable, including deletion (e.g., *self* → [sɛf]), substitution (e.g., *mask* → [mæst]), metathesis (e.g., *desk* → [dɛks]), or some combination of these repairs (e.g., *guest* → [gɛk]), suggesting that *COMPLEXCODA could not be the only constraint motivating these repairs (as substitution and metathesis do not satisfy *COMPLEXCODA). Despite the range of repair strategies employed in the production of coda consonant clusters, it is clear that this other type of complex structure is less well-formed in VBR's grammar than in the grammar of unimpaired English speakers, and thus requires some type of repair to minimize the complexity of the target.

4.3.2. Other markedness-reducing patterns

Given the evidence that the *COMPLEX family of markedness constraints is promoted in VBR's grammar, it is worth pursuing the question of whether there is something about this particular family of constraints that is likely to be promoted in cases of brain damage. A survey of other cases of aphasia reported in the literature indicates that some individuals make errors that appear to be driven by the same constraint family as VBR's (Béland, 1990; Béland and Paradis, 1997; Romani and Galluzzi, 2005), whereas there are others for whom this is not the case. In particular, two patients have been reported in-depth with a deficit that leads them to replace high sonority singleton consonant onsets, such as liquids and glides, with lower sonority onsets, such as obstruents (Romani and Calabrese, 1998; Stenneken et al., 2005; also see Béland et al., 1990; Blumstein, 1973, 1978; Buckingham, 1986). In these cases, we can identify the set of markedness constraints that have been promoted as the *ONSET/X constraints (Prince and Smolensky, 1993/2004; also see Baertsch and Davis, 2003; Smith, 2008). These constraints – part of the more general family of *MARGIN/X – penalize output forms for containing particular classes of sounds in particular syllabic positions, with the X referring to the natural class of sounds. There is a universal ranking among these constraints that generates the well-known typological fact that low sonority onsets are preferred to high sonority onsets (Clements, 1990): *ONSET/GLIDE ≫ *ONSET/RHOTIC ≫ *ONSET/LATERAL ≫ *ONSET/NASAL ≫ *ONSET/OBSTRUENT (from Smith, 2008).

Patient DB, reported by Romani and Calabrese (1998), was a native Italian aphasic speaker who made systematic errors when producing singleton onsets. In particular, DB's errors tended to improve the sonority profile of the target word by creating lower sonority onsets, and to remove onset consonant clusters via (in most cases) deletion of the second – more sonorous – consonant. These patterns may be accounted for if we assume that some of the *ONSET/X constraints have been promoted in DB's grammar relative to an unimpaired Italian speaker, and the pressure to avoid high sonority onsets drives both substitution and deletion repairs. Nevertheless, the avoidance of consonant clusters may also suggest that the *COMPLEX family was affected in DB's case as well.

Stenneken et al. (2005) reported patient KP, an aphasic German speaker whose production included frequent neologistic (nonword) forms. Stenneken et al. examined the syllabic content of KP's neologistic productions, and the analysis revealed that the sonority structure of the neologisms showed a strong tendency towards the preferred syllable types as defined according to sonority (see Clements, 1990) with significantly more preferred syllable types in the neologisms than occur in the German lexicon; that is, the effects of the *ONSET/X constraints could be observed in the

Please cite this article in press as: Buchwald, A., Minimizing and optimizing structure in phonology: Evidence from aphasia. J. Linguistics (2008), doi:10.1016/j.lingua.2007.11.015

patient's neologistic productions. KP also tended to avoid consonant clusters, suggesting that *COMPLEX may have also been promoted in KP's deficit.

In addition to these types of segmental constraints, other work has reported that aphasic individuals may have difficulty producing marked stress patterns (Cappa et al., 1997; Janssen, 2003), indicating that focal brain damage may lead to promotion of constraints against suprasegmental markedness as well.

4.3.3. *The nature of aphasic grammar*

This discussion has highlighted aphasic case studies in which markedness constraints appear to be promoted subsequent to brain damage, and it is worth noting that there are no known reports in which aphasia leads to more complex structure in output representations than in the phonological grammar of the language. That is, each reported case of impairment that appears to affect the phonological grammar may be analyzed as a case in which markedness constraints are elevated relative to (relevant) faithfulness constraints. One possible explanation for this pattern is that brain damage that affects phonological grammar causes the speaker's grammar to revert to an 'earlier' state with respect to acquisition. As has been argued by Tesar and Smolensky (1998, 2000), the initial state of constraint ranking is such that markedness constraints dominate faithfulness constraints, and acquisition may be best thought of as a process of constraint demotion based on the linguistic evidence to which the child is exposed (also see Boersma and Hayes, 2001, among others). Given the tendency for aphasic language to permit less complex structure, the idea that brain damage leads to the promotion of markedness constraints as a means of reverting to a more basic state of the grammar is an intriguing possibility, and this is indeed in the spirit of Jakobson's seminal claim that cross-linguistic distributions, language acquisition, and language loss all derive from the same set of principles.

On the surface, data such as those presented in this paper support this general claim. However, it remains unknown why some markedness constraints appear to be promoted relative to the relevant faithfulness constraints while others do not, and it is unlikely that the relative promotion of markedness constraints in aphasia is rooted in learning based on linguistic evidence (as has been argued for acquisition by Tesar and Smolensky, 2000; Boersma and Hayes, 2001 among many others). It is important for future work to address the root causes for particular constraints to be promoted (or demoted) subsequent to brain damage.

With respect to these patterns, there are several possibilities worth raising here for future consideration. It remains possible that families of markedness constraints which may be rooted in the simplification of articulatory patterns, enhancement of perceptual salience, or some other cognitive principle may be more likely to be promoted (possibly depending in part on the location of the lesion and the other cognitive systems which are affected). If the notion of constraint families is rooted in psychological reality (as discussed in Goldrick, submitted for publication) as has been suggested here, then we should continue to see patterns of individual aphasic speakers that exhibit the influence of promoted constraints in particular constraint families. It also remains possible that certain constraint families are neurally related to language-related cognitive systems responsible for production and perception, and that certain constraint families are more (or less) likely to be promoted depending on the individual deficit. It is hoped that future work on this topic will permit greater explanatory adequacy for why it is that certain patterns arise. (see Goldrick, in press, for a promising direction to address this issue in a Harmonic Grammar framework).

5. Concluding remarks

The work presented above supports the claim that the phonological processing system contains a grammatical component, and this level is constrained by markedness. In the case of impairment to this system, markedness helps to constrain output repairs. The case of VBR was explored, with several analyses dedicated to determining the level of processing at which her errors arise. VBR's performance was consistent with impairment to the post-lexical phonological processing system which has been argued to be the grammar component of the processing system, and converging evidence for this claim came from the ability to account for VBR's data in OT with basic changes between the grammar of American English and that of VBR. Although other cases in the literature suggest a variety of ways that markedness can constrain output forms in cases of brain damage, the effects of promoted markedness constraints for VBR served to minimize structural complexity in output forms. These converging lines of evidence provided clear and consistent support for the claim that the phonological processing system is constrained by factors that favor minimal structures.

Acknowledgments

This work would also not have been possible without the willing and friendly participation of VBR. I gratefully acknowledge the helpful comments of Paul Smolensky and Brenda Rapp over the course of this research. I also thank the audience at the Experimental Evidence for Minimal Structure workshop at DGfS in Siegen, 2007, Petra Burkhardt, Ulrike Domahs, Stuart Davis, Susannah Levi and two anonymous reviewers for extremely helpful and insightful comments on this research and earlier drafts of this paper. I am solely responsible for any errors or lack of insight.

References

Anttila, A., 1997. Deriving variation from grammar. In: Hinskens, F., van Hout, R., Wetzels, W.L. (Eds.), Variation and Change in Phonological Theory. John Benjamins, Amsterdam, pp. 35–68.

Baertsch, K., Davis, S., 2003. The split margin approach to syllable structure. In: Hall, T.A., Hamann, S. (Eds.), ZAS Papers in Linguistics, vol. 32. pp. 1–14.

Barlow, J., 1996. The development of on-glides in American English. Paper presented at the Boston University Conference on Language Development, Somerville, MA.

Barlow, J., 2001. Individual differences in the production of initial consonant sequences in Pig Latin. Lingua 111.

Béland, R., 1990. Vowel epenthesis in aphasia. In: Nespoulous, J.-L., Villiard, P. (Eds.), Morphology, Phonology, and Aphasia. Springer-Verlag, New York, pp. 235–252.

Béland, R., Paradis, C., 1997. Principled syllabic dissolution in a primary progressive aphasia case. Aphasiology 11, 1171–1196.

Béland, R., Caplan, D., Nespoulous, J.-L., 1990. The role of abstract phonological representations in word production: evidence from phonemic paraphasias. Journal of Neurolinguistics 5, 125–164.

Blevins, J., 1995. The syllable in phonological theory. In: Goldsmith, J. (Ed.), Handbook of Phonological Theory. Blackwell, Oxford (Chapter 6).

Blumstein, S.E., 1973. A Phonological Investigation of Aphasic Speech. Mouton, The Hague.

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

Blumstein, S.E., Cooper, W.E., Goodglass, H., Statlender, S., Gottleib, J., 1980. Production deficits in aphasia: a voice-onset time analysis. Brain and Language 9, 153–170.

Boersma, P., 1998. Functional Phonology. UCLA, Los Angeles, CA.

Boersma, P., Hayes, B., 2001. Empirical tests of the Gradual Learning Algorithm. Linguistic Inquiry 32, 45–86.

Borowsky, T., 1984. On resyllabification in English. Paper presented at the West Coast Conference on Formal Linguistics (WCCFL), p. 3.

Buchwald, A., 2005. Sound structure representation, repair and well-formedness: Grammar in spoken language production. Unpublished Ph.D. dissertation, Johns Hopkins University, Baltimore, MD.

Buchwald, A., 2006. Representing sound structure: evidence from aphasia. In: Alderete, J., Han, C.-H.H., Kochetov, A. (Eds.), 24th West Coast Conference on Formal Linguistics, Vancouver, BC. Cascadilla Proceedings Project, Somerville, MA, pp. 79–87.

Buchwald, A., 2007. Determining well-formedness in phonology: type vs. token frequency. Paper presented at the 81st Annual Meeting of the Linguistics Society of America.

Buchwald, A., Rapp, B., Stone, M., 2007. Insertion of discrete phonological units: an ultrasound investigation of aphasic speech. Language and Cognitive Processes 22, 910–948.

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

Cappa, S.F., Nespor, M., Ielasi, W., Miozzo, A., 1997. The representation of stress: evidence from an aphasic patient. Cognition 65, 1–13.

Caramazza, A., 1986. On drawing inferences about the structure of normal cognitive systems from the analysis of patterns of impaired performance: the case for single-patient studies. Brain and Cognition 5, 41–66.

Chomsky, N., Halle, M., 1968. The Sound Pattern of English. Harper and Row, New York, NY.

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

Clements, G.N., Hume, E.V., 1995. The internal organization of speech sounds. In: Goldsmith, J.A. (Ed.), The Handbook of Phonological Theory. Blackwell, Cambridge, MA.

Davidson, L., 2003. The atoms of phonological representation: gestures, coordination, and perceptual features in consonant cluster phonotactics. Unpublished Ph.D. Dissertation, Johns Hopkins University, Baltimore, MD.

Davidson, L., 2005. Addressing phonological questions with ultrasound. Clinical Linguistics and Phonetics 19, 619–633.

Davidson, L., 2006. Phonotactics and articulatory coordination interact in phonology: evidence from non-native production. Cognitive Science 30, 837–862.

Davidson, L., Goldrick, M., 2003. Tense, agreement and defaults in child Catalan: an Optimality Theoretic analysis. In: Montrul, S., Ordóñez, F. (Eds.), Linguistic Theory and Language Development in Hispanic Languages. Cascadilla Press, Cambridge, MA, pp. 193–211.

Davidson, L., Stone, M., 2004. Epenthesis versus gestural mistiming in consonant cluster production. Paper presented at the West Coast Conference on Formal Linguistics (WCCFL), vol. 22, University of California, San Diego.

Davidson, L., Smolensky, P., Jusczyk, P., 2004. The initial and final states: theoretical implications and experimental explorations of richness of the base. In: Kager, R., Zonneveld, W., Pater, J. (Eds.), Fixing Priorities: Constraints in Phonological Acquisition. Cambridge University Press, Cambridge, pp. 321–368.

Davis, S., Hammond, M., 1995. On the status of onglides in American English. Phonology 12, 159–182.

Dogil, G., Mayer, J., 1998. Selective phonological impairment: a case of apraxia of speech. Phonology 15, 143–188.

Edwards, J., Beckman, M.E., 2008. Some cross-linguistic evidence for modulation of implicational universals by language-specific frequency effects in phonological development. Language Learning and Development 4, 122–156.

Goldrick, M., submitted for publication. Psychological reality and its implications for phonological theory. In: Goldsmith, J.A., Riggle, J., Yu, A.C.L. (Eds.), Handbook of Phonological Theory, 2nd edition. Blackwell.

Goldrick, M., in press. Linking speech errors and phonological grammars: Insights from Harmonic Grammar networks. Phonology.

Goldrick, M., Rapp, B., 2007. Lexical and post-lexical phonological representations in spoken production. Cognition 102, 219–260.

Greenberg, J.H., 1978. Typology and cross-linguistic generalizations. In: Greenberg, J.H. (Ed.), Universals of Human Language, vol. I. pp. 33–59.

Halle, M., Mohanan, K.P., 1985. Segmental phonology of modern English. Linguistic Inquiry 16, 57–116.

Harris, J.W., Kaisse, E.M., 1999. Palatal vowels, glides and obstruents in Argentinian Spanish. Phonology 16, 117–190.

Jakobson, R., 1941/1968. Child Language, Aphasia, and Phonological Universals. Mouton, The Hague.

Janssen, U., 2003. Stress assignment in German patients with surface dyslexia. Brain and Language 87, 114–115.

Kay, J., Lesser, R., Coltheart, M., 1992. PALPA: Psycholinguistic Assessments of Language Processing in Aphasia. Lawrence Erlbaum Associates, Hove.

Kenstowicz, M., 2006. Generative phonology. In: Brown, K. (Ed.), Encyclopedia of Language and Linguistics, vol. 5. Elsevier, London, pp. 1385–1396.

Legendre, G., Hagstrom, P., Chen-Main, J., Tao, L., Smolensky, P., 2004. Deriving output probabilities in child mandarin from a dual optimization grammar. Lingua 114, 1147–1185.

Lombardi, L., 1990. The nonlinear organization of the affricate. Natural Language and Linguistic Theory 8, 375–425.

Morelli, F., 1999. The Phonotactics and Phonology of Obstruent Clusters in Optimality Theory. University of Maryland, College Park, MD.

Paradis, C., Prunet, J.-F. (Eds.), 1991. The Special Status of Coronals: Internal and External Evidence. Academic Press, San Diego, CA.

Pater, J., Barlow, J.A., 2003. Constraint conflict in cluster reduction. Journal of Child Language 30, 487–526.

Prince, A., Smolensky, P., 1993/2004. Optimality Theory: Constraint interaction in generative grammar (Technical report). Rutgers University, New Brunswick and University of Colorado, Boulder. Revised version published by Blackwell, 2004.

Rapp, B., Goldrick, M., 2006. Speaking words: contributions of cognitive neuropsychological research. Cognitive Neuropsychology 23, 39–73.

Romani, C., Calabrese, A., 1998. Syllabic constraints on the phonological errors of an aphasic patient. Brain and Language 64, 83–121.

Romani, C., Galluzzi, C., 2005. Effects of syllabic complexity in predicting accuracy of repetition and direction of errors in patients with articulatory and phonological difficulties. Cognitive Neuropsychology 22, 817–850.

Romani, C., Olson, A., Semenza, C., Granà, A., 2002. Patterns of phonological errors as a function of a phonological versus articulatory locus of impairment. Cortex 38, 541–567.

Sagey, E., 1986. The Representation of Feature and Relations in Nonlinear Phonology. MIT, Cambridge, MA.

Smith, J.L., 2008. Phonological constraints are not directly phonetic. Proceedings of the Chicago Linguistics Society (CLS) 41, 457–472.

Smolensky, P., 2006. Optimality in phonology II: markedness, feature domains, and local constraint conjunction. In: Smolensky, P., Legendre, G. (Eds.), The Harmonic Mind: From Neural Computation to Optimality-Theoretic Grammar. MIT Press, Cambridge, MA.

Stenneken, P., Bastiannse, R., Huber, W., Jacobs, A.M., 2005. Syllable structure and sonority in language inventory and aphasic neologisms. Brain and Language 95, 280–292.

Steriade, D., 1988. Review of Clements & Keyser (1983). Language 64, 118–129.

Stone, M., 1991. Imaging the tongue and the vocal tract. British Journal of Disorders of Communication 26, 11–23.

Tesar, B., Smolensky, P., 1998. Learnability in Optimality Theory. Linguistic Inquiry 29, 229–268.

Tesar, B., Smolensky, P., 2000. Learnability in Optimality Theory. MIT Press, Cambridge, MA.

Trubetzkoy, N., 1939/1969. Principles of Phonology (Translation of Grundzüge der Phonologie). University of California Press, Berkeley.

Zuraw, K.R., 2000. Patterned exceptions in phonology. Unpublished Ph.D. dissertation, UCLA, Los Angeles, CA.

Please cite this article in press as: Buchwald, A., Minimizing and optimizing structure in phonology: Evidence from aphasia. J. Linguistics (2008), doi:10.1016/j.lingua.2007.11.015