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Evidence for discrete phonological representations in production: Ultrasound imaging of aphasic speech

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Introduction

Theories of spoken language production posit several levels at which production errors may arise (e.g., lexical selection; phonological encoding; articulatory planning), and aphasic speech errors have helped uncover the nature of the computations and mental representations active at these levels. Recent research reveals that certain speech production errors may be detected only with acoustic or articulatory measurement, and these results (among others) have been used to argue against the existence of discrete (e.g., segmental) representations of sound structure (see Pouplier & Hardcastle, 2005, for a review). However, this acoustic and articulatory research rarely identifies the locus of the production errors, complicating attempts to understand how sound structure is represented at different points in the language production system. While it is clear that spoken language production requires gradient representations that interact with systems responsible for motor planning and implementation, the evidence does not necessarily preclude a level of segmental representation as well Fig. 1.

The present work combines a behavioral study of an aphasic individual (that serves to identify the locus of production errors) with an articulatory ultrasound imaging study designed to clarify the nature of the observed errors. We show that this technique, well-suited to provide evidence of continuous sound structure representations, nonetheless provides clear support for a segmental level of phonological representation.

We report on VBR, an aphasic speaker whose spoken productions contain a systematic 'repair': schwa-like vowels are perceived to be inserted in most word-initial consonant clusters (e.g., *clone arrow* c[ə]lone). Under one account (*Epenthesis*), the insertion is the result of inserting a discrete vowel unit into the planned utterance, such that *clone* is produced identically to *cologne*. The second account (*Mistiming)* holds that the perception of an inserted vowel simply reflects a systematic mistiming of dynamic articulatory gestures associated with the production of the two consonants (Davidson, 2003), with these gestures 'pulled apart'. The latter account does not require positing segmental units.

To test these possibilities, VBR was asked to produce words with onset consonant (C_1C_2) clusters (e.g., *clone*) in which she typically inserted a vowel, and matched words containing a lexical vowel in similar phonological environments (C_1VC_2; e.g., *cologne*). Her articulations were recorded with ultrasound imaging, which provides a rendering of tongue movements during running speech. This allowed us to address the predictions of two main accounts of vowel insertion and the implications these have for theories of phonological representation.

Case report

VBR, 58, is a right-handed woman who suffered a cerebral-vascular accident (CVA) six years prior to the onset of the investigation (2/2004), producing severe spoken language difficulties. MRI reveals a large left hemisphere fronto-parietal infarct affecting Broca's area, pre- and post-central gyri and the supramarginal gyrus.

Analysis 1: Localization of deficit

VBR performed with similar accuracy in picture naming (64% words correct; 85% phonemes), reading (67% words; 85% phonemes), and repetition (67% words; 86% phonemes). Importantly, errors on these tasks are also qualitatively similar, consisting primarily of single phoneme insertions, substitutions, deletions, etc. Vowel insertion in consonant clusters was observed in all tasks. The similar performance in these tasks suggests a spoken production deficit affecting post-lexical phonological processing (following Goldrick & Rapp, in press).

Analysis 2: Articulatory measures

Ultrasound measurements

Mid-sagittal images of the tongue were collected using a commercially available ultrasound machine (Acoustic Imaging Inc., Model AI5200S). VBR was asked to produce 22 pairs of inserted vowel-lexical vowel (e.g., *clone-cologne*) words while ultrasound images were collected. Each word was produced four times in succession.

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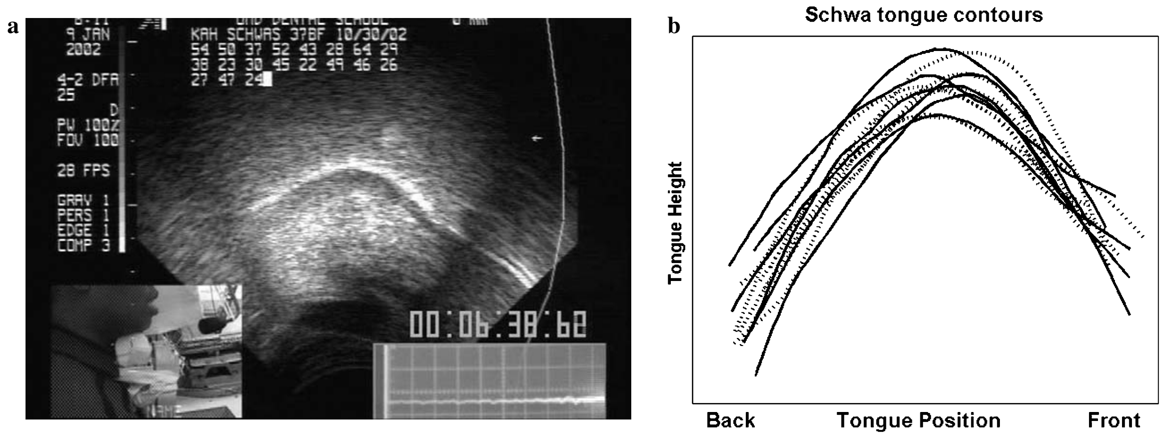

Fig. 1. (a) shows sample mid-sagittal tongue image recorded from ultrasound. The tongue tip is oriented to the right, conforming to the image of the speaker in the photo overlay. (b) shows VBR's inserted (solid lines) and lexical (dotted lines) schwa tongue contours extracted from subset of words (glue/galoot; clue/collude) matched for place of C1, C2, and following vowel. Note the lack of a clear distinction between inserted and lexical schwa.

Ultrasound analysis and results

The ultrasound images (30/s) contain a thick white line representing the tongue whose contour reflects the positioning of the tongue in the vocal tract (see Figure). For each utterance, tongue contours representing C1, C2, and the inserted or lexical vowel were extracted based on articulatory and acoustic cues. RMS (root mean square) comparisons of the tongue contours were made within word pairs (e.g., clone-cologne). According to the *Epenthesis* account, the contours representing the four inserted vowels and four lexical vowels for each word pair should be from the same population; thus, differences between vowel types (Inserted and Lexical) should be the same as the variation within each group. Inserted vowels contours should also be more similar to lexical vowels than to the consonant tongue contours. The *Mistiming* account predicts smaller differences within each vowel type than across the vowel types, as these two vowels are the result of executing different articulatory plans.

A comparison within each vowel type (lexical: mean RMS = 2.33; inserted: mean RMS = 2.09) and across vowel types (mean RMS = 2.23) yielded no significant differences, $F(2,519) = 1.12$, *ns* (see Figure). Inserted vowels were also compared consonant tongue contours and to C1 (mean RMS = 5.22) and C2 (mean RMS = 3.12). Planned comparisons yielded significantly smaller RMS values between inserted vowels and lexical schwa than between: inserted vowels and $\mathbf{C}_2$, $t\,(680) = 9.78$, $p < .001$; and between inserted vowels and $\mathbf{C}_1$, $t\,(467) = 27.45$, $p < .001$. These data are consistent only with the *Epenthesis* account of vowel insertion.

Conclusions

The ultrasound study reveals no difference between VBR's productions of C_1C_2 words with schwa inserted between C1 and C2 (e.g., clone) and C_1VC_2 words (e.g., cologne), inconsistent with the *Mistiming* account. This result is consistent with the *Epenthesis* account, and a level of post-lexical phonological processing in which representations may be 'repaired' via insertion of the same discrete phonological units used to distinguish among forms in the lexicon (e.g., segments). Acoustic analyses supporting these conclusions will also be presented. While undoubtedly there is a level of continuous representation of sound structure, the evidence we report indicates that a categorical, segmental level of phonological representation must also be assumed.

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