Introduction

Theories of speech and language production have long posited a distinction between context-independent representations of sound structure (e.g., a linear string of phonemes; Garrett, 1980; Dell, 1986) and context-dependent representations of sound structure (e.g., a gestural score indicating spatial and temporal coordination among neighboring gestures; Browman & Goldstein, 1986). While this distinction might suggest that there should be a clear distinction between impairment to these two levels, empirical support of a clear distinction has been elusive. In particular, it is now generally accepted that articulatory errors can arise subsequent to either acquired phonological impairment in phonemic paraphasia (PP) or motor speech impairment as in Apraxia of Speech (AOS), with the latter more clearly associated with prosodic abnormalities (McNeil, Pratt, & Fossett, 2004; McNeil, Robin, & Schmidt, 2009; Wambaugh, Duffy, McNeil, Robin, & Rogers, 2006). The issue is further complicated by the high rates of comorbidity of PP and AOS. At this point, the question arises whether we can identify the locus of articulatory errors when presented with an individual with acquired impairment who makes such errors in their speech production. That is, can we determine whether particular errors come from phonological impairment or motor planning impairment?

In this paper, we report on analyses from two individuals who make similar errors – /s/-deletion from word-initial /s/-clusters (e.g., *<u>sp</u>ill*; *<u>sm</u>all*). While each individual deletes /s/ in their production, P1's errors are consistent with the timing associated with a singleton consonant (i.e., the timing does not reflect the /s/ that was deleted) whereas P2's errors reflect the timing associated with a consonant cluster. We use these patterns to argue that P1's deletion error arises before context-specific representations have been generated, whereas P2's errors arise after these representations were generated. These results lend empirical support to the claim that there are these two distinct levels of sound structure processing, and may have additional usefulness in elaborating accounts of the differential diagnosis of PP and AOS.

Method

The participants were two individuals with acquired aphasia subsequent to left-hemisphere MCA stroke. Demographic information is available in Table 1. Each individual was anomic and showed signs of articulatory impairment, and each was diagnosed with both PP and AOS by a licensed speech-language pathologist. In addition, each individual made frequent /s/-deletion errors from words with onset consonant clusters beginning with /s/ (P1: 51%; P2: 20%). Given their other impairments in word generation and retrieval, participants were tested with repetition tasks designed exclusively for this study. To verify that the participants were capable of auditory speech perception which is a necessary component of repetition, we used both standardized and novel minimal pair discrimination tasks, reported in Table 2. The data presented here come from weekly testing sessions over a period of approximately six months. Each individual was in therapy during the testing period, but did not work on articulatory issues related to /s/.

VOT. Each participant repeated /s/-stop clusters (e.g., *spill~still~skill*), control words beginning with both the voiceless stop (e.g., *pill~till~kill*) and control words beginning with the voiced stop (e.g., *bill~dill~gill*). Control words were matched for stop consonant place of articulation, following vowel, and phonemic length. For unimpaired English speakers, the stop produced in clusters is unaspirated, and has a VOT equivalent to the voiced stop (Lisker &

Abramson, 1964). Thus, if the /s/ is deleted after the context-specific timing is generated, the resulting stop should be unaspirated with a VOT shorter than the voiceless stop. In contrast, if /s/ is deleted prior to generating the context-specific timing for the cluster, then the resulting stop should be aspirated, and longer than the voiced stop.

Nasal duration. Each participant was presented with words to produce containing /s/-nasal clusters (e.g., *smear, sneer*). For each cluster word, participants were presented with control words that contained the singleton nasal (*mere; near*). Control words were matched for nasal identity, following vowel, and phonemic length. In unimpaired speech, the nasal consonants are shorter in the cluster than as singletons (Klatt, 1975). Thus, if /s/ is deleted from /s/-nasal clusters after context-dependent timing is generated, then the resulting nasal should be shorter than singleton nasals in the same word (e.g., *m* in *~~s~~mile* should be shorter than *m* in *mile*). In contrast, if the /s/ is deleted before context-specific timing is generated, then no differences should be obtained.

All repetition tasks were recorded for later acoustic and transcription analysis. Two trained research assistants listened to each token to determine whether /s/ was deleted, using both perceptual judgments and spectrographic information. All deletion tokens discussed below were agreed upon by both scorers.

Results

VOT. P1's /s/-deletion errors in /s/-stop clusters yielded output forms similar in VOT to the voiceless stop (e.g., *~~s~~pill* → *pill*), and significantly longer than the voiced stop (Figure 1), consistent with the context-specific timing of a singleton voiceless stop. In contrast, P2's deletion errors in /s/-stop clusters yielded output forms with significantly shorter VOTs than the voiceless stops, similar to the voiced stops (e.g., *~~s~~pill* → *bill*); thus, P2's productions consistent with the context-specific timing of the cluster. No velar tokens are listed for P2 as he was unable to produce these accurately as singletons or clusters.

Nasal duration. P1's /s/-deletion errors in /s/-nasal clusters did not yield significantly different nasal durations than matched singleton nasals. In contrast, tokens in which P2 deleted /s/ from /s/-nasal clusters had a significantly shorter nasal duration than the control words. See Figure 2 for details.

Discussion and Conclusion

The data presented here reveal a clear and consistent difference between two types of /s/-deletion. In the first pattern, exhibited by P1, the output form following /s/-deletion reflects the articulatory timing that would expected if that timing was generated based on a singleton onset (and not a cluster). Results from VOT and nasal duration analyses were consistent with P1's /s/-deletion taking place prior to the generation of context-specific articulatory timing. The second pattern, exhibited by P2, reflects the articulatory timing associated with an /s/-initial consonant cluster, even when the /s/ has been deleted from the output form. These two patterns lend support to the hypothesis that there are both context-independent and context-specific levels of sound structure processing, and that errors may arise at either level subsequent to brain damage.

Despite diagnostic evaluations indicating that each individual presented with both AOS and PP, the different acoustic patterns reveal that the /s/-deletion errors arise at different levels in speech production: while P1's errors arise in phonological processing, P2's errors arise at a level reflecting motor speech planning. Consistent with this characterization, a post hoc analysis of the performance of P1 and P2 reveal very different patterns as a result of practice: P1's cluster production performance did not change over time, whereas P2 showed a marked increase in performance over the course of the study (see Figure 3). These data may be consistent with the differences among errors arising during phonological processing and errors arising during motor processing, the latter of which more directly benefit from practice. Taken together, the acoustic results and the change in accuracy suggest that specific errors in impaired individuals with

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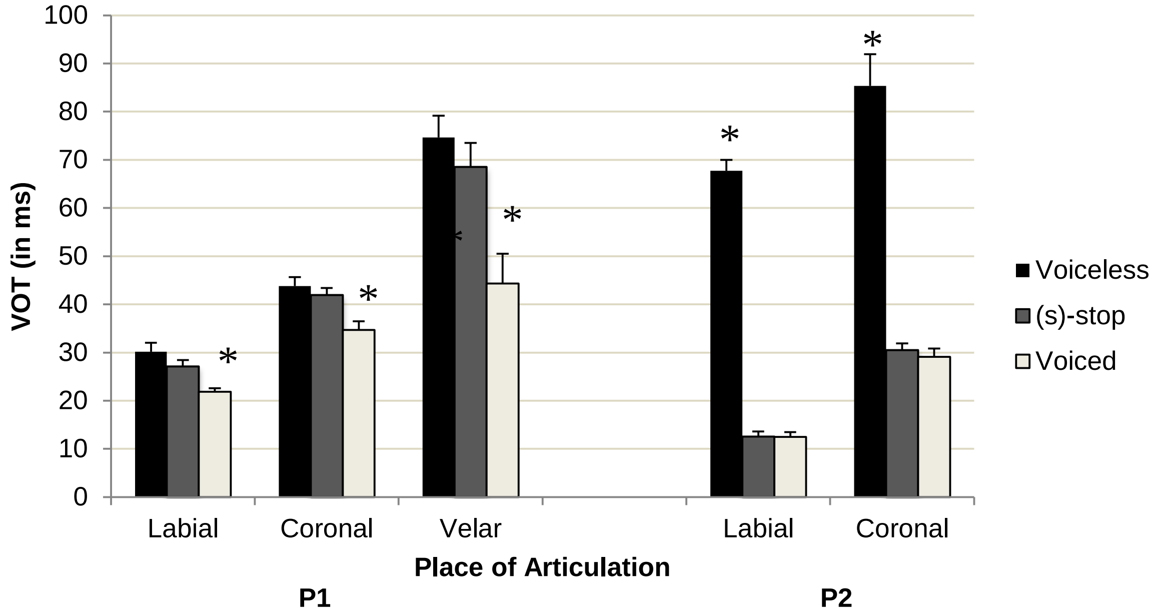
Table 1: Participant Demographic Information and standardized Test Performance

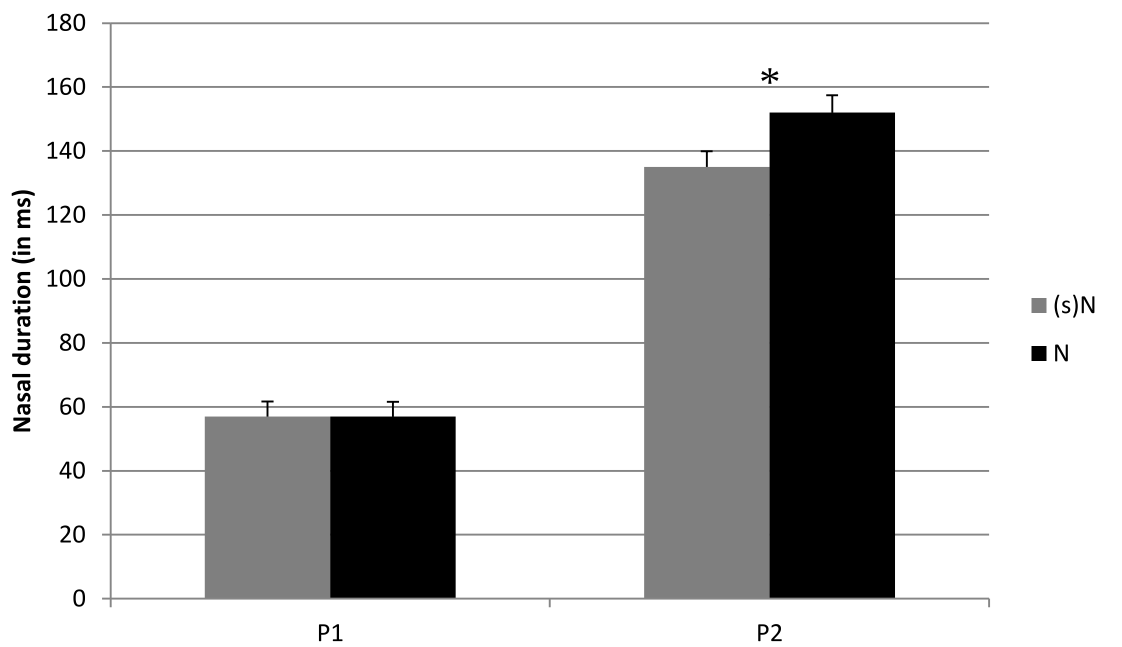
	P1	**P2**
Age (years)	76	60
Education (years)	17	21
Time Post Onset (months)	84	30
Handedness	Left	Right
Naming: *Boston Naming Test*		
BNT (full)	33/60	
Short form		1/15
Comprehension: *PPVT*	43rd percentile	4th percentile
Articulation: *ABA-2*		
Subtest 1	Mild	Mild
Subtest 2A	Severe	Moderate
Subtest 2B	Moderate	Severe
Subtest 3A	Mild	Mild
Subtest 3B	Moderate	Moderate
Subtest 4	Severe	Severe
Subtest 5	Moderate	Severe
Aphasia Quotient: *WAB-R*	Not administered	41.1 (Broca's)

Table 2: Participant performance on minimal pair discrimination tasks.

	P1		**P2**	
Task	Same	Different	Same	Different
Words from PALPA 2	35/36 z=-.69	36/36 z=+.45	36/36 z=+.58	36/36 z=+.45
spill-pill	59/60 (98%)	60/60 (100%)	80/81 (99%)	35/36 (98%)
spill-bill	58/60 (97%)	49/60 (82%)	80/81 (99%)	32/32 (100%)



<u>Figure 1</u>: VOT for both P1 and P2 plotted as a function of place of articulation and target word type. (s)-stop refers to the tokens with target /s/-stop clusters for which the /s/ was deleted. Error bars represent standard error. Asterisks (*) denote significantly different from VOT of (s)-stop token of the same place of articulation (α=.05).



<u>Figure 2</u>: Nasal duration P1 and P2 plotted as a function of target word type. (s)N refers to the tokens with target /s/-nasal clusters for which the /s/ was deleted. Asterisks (*) denote significant differences (α=.05).

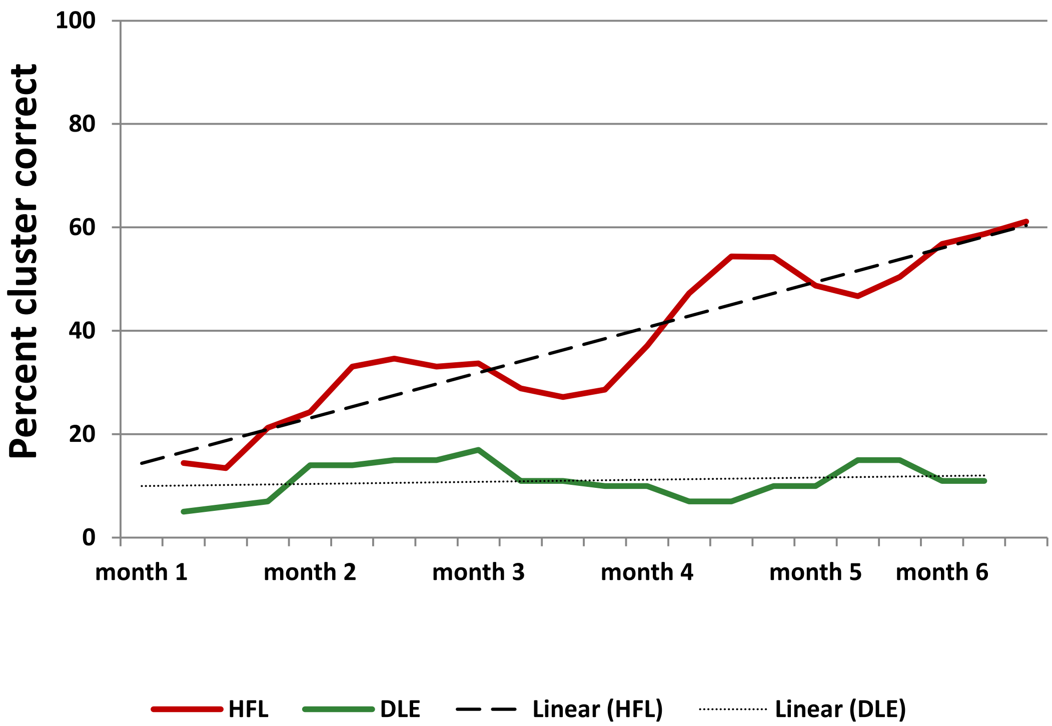


Figure 3: Accuracy in producing /s/-stop and /s/-nasal clusters over the course of testing. These data represent overall accuracy, with linear trendlines indicating the overall pattern.