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Variability in Apraxia of Speech: A Perceptual, Acoustic, and Kinematic Analysis of Stop Consonants

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Variability in Apraxia of Speech: A Perceptual, Acoustic, and Kinematic Analysis of Stop Consonants

Since being recognized as a clinical entity, the defining characteristics of apraxia of speech (AOS) have continued to evolve (McNeil, Robin, & Schmidt, 1997). Early research examining speech production with AOS speakers revealed inconsistency in articulatory performance with unpredictable errors (Johns & Darley, 1970; LaPointe & Johns, 1975). More recent research with "pure" apraxic speakers and AOS speakers with accompanying aphasia has revealed consistency in the location and types of errors in repeated productions (McNeil, Odell, Miller & Hunter, 1995; Shuster & Wambaugh, 2003; Wambaugh, Nessler, Bennett & Mauszycki, 2004). The issue of variability in AOS remains unresolved (Croot, 2002). In particular, there are limited data regarding variability in performance over time (i.e., beyond a single testing session). Additionally, most information concerning variability in AOS has been derived from perceptual data.

The purpose of this investigation was to examine articulatory variability in an individual with AOS and aphasia. Of particular interest was the consistency of stop consonant productions over repeated sampling examined via perceptual, acoustic, and kinematic analyses.

Method

Participants

Two speakers participated in the study. The first was a male who presented with moderate AOS and non-fluent aphasia. The second was a male with normal speech/language who served as the control speaker. See Table 1 for further description.

Instrumentation

Lip and jaw movements were transduced with a head-mounted strain gauge system (Barlow, Cole, & Abbs, 1983). Inferior-superior displacements of the upper lip, lower lip, and jaw were recorded using cantilever beams instrumented with strain gauges attached to the head-mounted frame. A microphone was mounted onto the headset frame to capture the speech signal.

Experimental Stimuli

Eighteen CVC words beginning with an initial stop consonant were chosen for study. Four to five exemplars were selected for each of the following sounds: /b, p, d, t/.

Speech Sample

One of the authors, who was familiar to the participant with AOS, conducted the sampling. The examiner read each word, following a schwa (e.g., 'a pill') and requested that the speaker produce the item five times with no feedback provided regarding accuracy. The control speaker read each word five times in succession. The words were elicited in random order for a total of 450 words.

For the control speaker, the stimuli were elicited in one session. For the AOS speaker, the stimuli were repeatedly elicited on three different days. The first two sessions were conducted on consecutive days at the same time both days. The third was conducted a week later on the same day of the week and the same time of day as the initial administration. The corpus of data was utilized in the perceptual analysis. However, a subset of tokens were utilized in the acoustic and kinematic analyses, which included 10 tokens of each target word on each day for a total of 180 words for each sampling occasion. Primarily, accurate tokens were utilized for acoustic and kinematic analyses, but erroneous productions were included unless the manner of production was in error.

Perceptual analysis

Productions were transcribed using narrow phonetic transcription (Shriberg & Kent, 1982).

Acoustic analysis

The speech data were digitized at 48 kHz and stored using Computerized Speech Lab (Kay Elemetrics, 2001). Spectrographic and oscillographic displays were produced and linked to measure voice onset time (VOT) of the initial stop consonants and total word duration (TWD). VOT was measured from the onset of the noise burst to the onset of periodic energy and TWD was also measured from the onset of noise burst to the point of a reduction in amplitude to baseline.

Kinematic analysis

The upper lip, lower lip, and jaw movement signals, which were digitized at 1 kHz per channel, were exported as binary files and imported into MATLAB (Mathworks, 2001) for analysis with custom routines. Although signals from all three articulators were recorded, the present analysis is focused on the movements of the lower lip and jaw. Three kinematic measures were conducted: 1) *utterance duration,* measured from the first velocity peak to the final velocity peak in target words; 2) *displacement and peak velocity,* measured for the selected closing movement and was computed using a simple two-point difference method in MATLAB; 3) *spatiotemporal index (STI)* was calculated utilizing methods developed by Smith, Goffman, Zelaznik, Ying, and McGillem, 1995.

Results

Perceptual Analyses

Percentages of Sounds in Error

The percentage of sounds in error was calculated for each sound at each sampling time for the AOS speaker (Table 2). The percentages of errors for three of the stop consonants /b, p, t/ were more variable across sampling times. The percentages of errors for /d/ were similar across sampling times.

Similarity of Errors

The errors that occurred for each sound by the AOS speaker were examined to determine if the same type of error occurred across the different words of that sound. The percentage of same errors was high (i.e., > 75%) across all sounds when errors occurred (Table 3).

Type of Errors

The errors produced by the AOS speaker were categorized with the broad error classes of 1) voicing errors, 2) distortions, and 3) placement errors. Voicing errors were the most prevalent type of error (Table 4).

Errors on Individual Words

The percentage of words that contained the same error across sampling times was examined (i.e., time 1 vs. 2) and revealed that performance on specific words was not highly predictable (Table 5).

Acoustic Analyses

Voice Onset Time

The mean VOT value and coefficient of variation is presented for each sound in Table 6 for both speakers and sampling times. For voiced sounds, both speakers were similar in mean values across sampling times, but the AOS speaker demonstrated greater variability (larger coefficients of variation). Findings were similar for voiceless sounds, but there was an increase in VOT values over subsequent sampling times for the AOS speaker.

Total Word Duration

The average TWD by sound are represented in Figure 1. The mean values for the AOS speaker were longer and tended to be more variable regardless of sound or sampling time.

Kinematic Analyses

Duration

Figure 2 illustrates the mean utterance duration for each sound. The AOS speaker had longer utterance durations and the durations became progressively longer over subsequent sampling times.

Displacement & Peak Velocity

Findings for displacement of the lower lip plus jaw during the closing movement are presented in Table 7. Mean displacement values were greater for the AOS speaker. Interestingly, the AOS speaker had less variability than the control speaker for three of the stop consonants (i.e., /p, d, t/).

The average peak velocities for each sound are displayed in Table 8. Peak velocities for the lower lip plus jaw were larger and considerably more variable for the AOS speaker.

Spatiotemporal Index

The spatiotemporal index examined the consistency of kinematic patterns across repetitions of words and sampling times (see Figure 3). The AOS speaker had higher STI values (i.e., increased variability) for bilabial stop consonants in contrast to the control speaker. The converse was found for alveolar stop consonants with lower STI values (i.e., less variability) for the apraxic speaker.

Conclusions

These findings indicate errors in AOS may vary across sounds with greater predictability for some sounds. Findings also revealed different patterns of variability for sounds. The implications of these findings will be discussed.

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Table 1
Characteristics of Speakers

Characteristics	AOS Speaker	Control Speaker
Age	38	24
Gender	Male	Male
Native Language	English	English
Years of Education	12	16
Occupation	Construction (former)	Student
Etiology	Brain Injury	na
Months Post-onset	23	na
Speech Production	AOS*	Unimpaired

* = Characteristics as described by McNeil, Robin, & Schmidt (1997)

Table 2
Percentage of Target Sounds in Error

Sound	T1	T2	T3
b	na	2%	6%
p	3%	3%	na*
d	3%	3%	2%
t	na	6%	4%
Total	1%	3%	3%

T = time (e.g., T1 = Sampling Time 1)
na = not applicable; no errors
* = only 1 error

Table 3
Percentage of same errors within sampling time by sound: Number of same errors/total number of errors (% same)

Sound	T1	T2	T3
b	na	2/2 100%	7/7 100%
p	3/4 75%	2/3 75%	na*
d	2/3 75%	2/3 75%	2/2 100%
t	na	5/6 83%	3/4 75%
total	71%	79%	92%

na = not applicable; no errors
* = only 1 error

Table 4
Types of Errors

Sampling	Voicing Errors	Distortions	Placement Errors
Time 1	57%	43%	na
Time 2	36%	28%	36%
Time 3	50%	43%	7%

na = not applicable; no errors

Table 5
Percentage of same words in error on repeated sampling

Comparison	
Time 1 vs. Time 2	10%
Time 1 vs. Time 3	19%

Table 6
VOT values in milliseconds (coefficient of variation)

Sound	Control	AOS-T1	AOS-T2	AOS-T3
b	15.5 (11.0)	16.3 (13.6)	16.9 (16.6)	14.7 (17.1)
p	76.7 (10.9)	72.7 (31.2)	108.6 (28.5)	118.1 (28.5)
d	18.5 (17.8)	18.7 (15.1)	18.2 (28.1)	17.4 (24.6)
t	89.4 (5.0)	89.3 (13.7)	126.6 (5.8)	129.4 (14.5)

Table 7
Displacement values in millimeters (coefficient of variation).

Sound	Control	AOS-T1	AOS-T2	AOS-T3
b	8.3 (10.4)	17.5 (11.9)	19.0 (13.5)	17.4 (12.6)
p	8.8 (14.6)	17.6 (11.0)	15.6 (12.7)	17.8 (12.6)
d	4.1 (23.5)	12.0 (12.8)	11.8 (13.6)	11.4 (11.0)
t	5.7 (17.6)	19.1 (12.0)	20.5 (12.7)	18.5 (12.2)

Table 8
Peak velocity values in millimeters/second (coefficient of variation).

Sound	Control	AOS-T1	AOS-T2	AOS-T3
b	63.0 (16.6)	119.8 (29.4)	161.4 (18.3)	148.4 (22.6)
p	62.2 (21.8)	139.3 (22.0)	82.2 (24.5)	71.4 (34.5)
d	22.5 (31.4)	62.5 (26.2)	53.4 (36.5)	54.0 (25.4)
t	57.4 (22.2)	138.5 (27.8)	134.8 (38.2)	120.8 (23.0)

Figure Captions

Figure 1. Summary of mean total word duration (colored bars) in milliseconds and coefficient of variation (error bars) by initial stop consonant.

Figure 2. Summary of mean kinematic utterance duration (colored bars) in milliseconds and coefficient of variation (error bars) by initial stop consonant.

Figure 3. Spatiotemporal index (STI) mean values for lower lip plus jaw by initial stop consonant.

Figure 1.

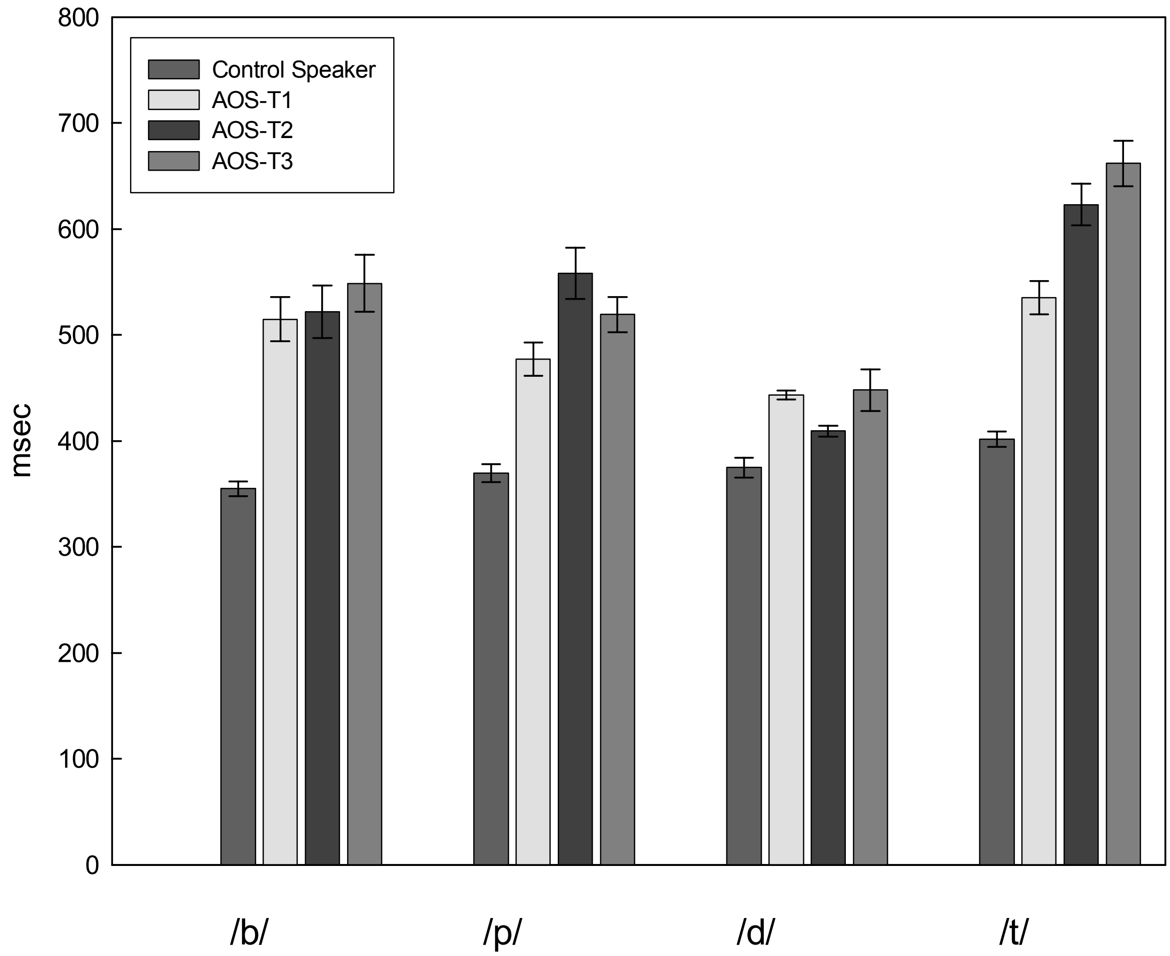
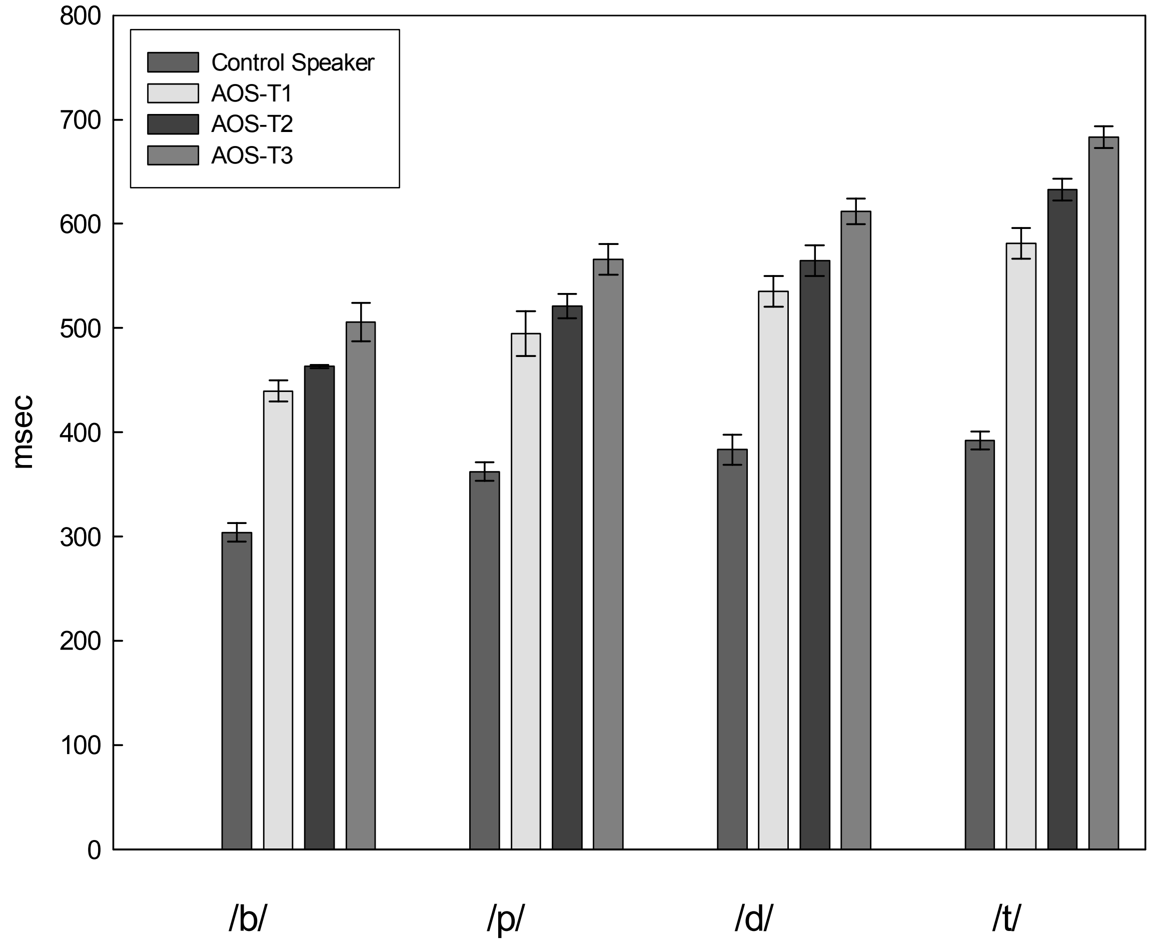

800
700
600
500
400
300
200
100
0
msec
Control Speaker
AOS-T1
AOS-T2
AOS-T3
/b/
/p/
/d/
/t/

Figure 2.


800
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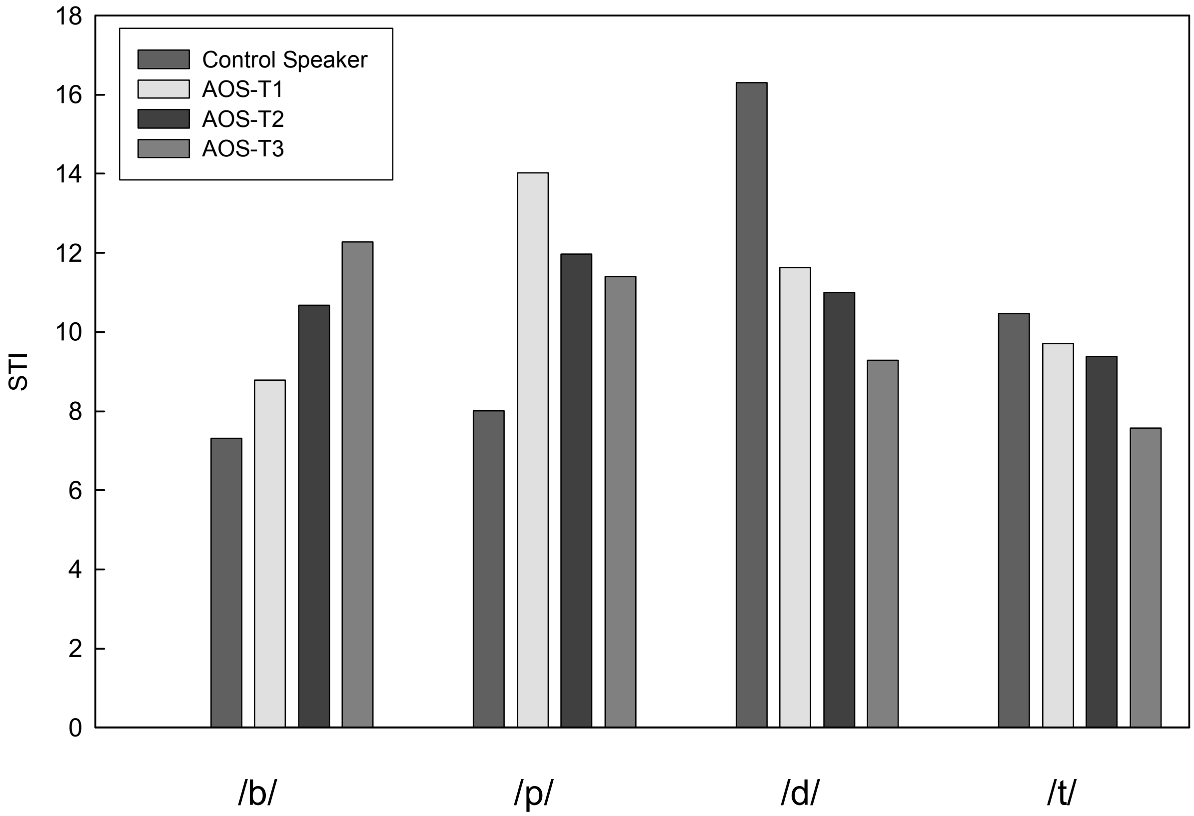
Control Speaker
AOS-T1
AOS-T2
AOS-T3
/b/
/p/
/d/
/t/

Figure 3.


Control Speaker
AOS-T1
AOS-T2
AOS-T3
STI
18
16
14
12
10
8
6
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/b/
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/d/
/t/