Acoustics of apraxia

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1 Background

(1) This handout is a summary of Kent and Rosenbeck (1983)

(2) Apraxia: "Apraxia of speech is a sensorimotor speech disorder resulting from brain damage."

(3) Characteristics
   a. A predominance of articulatory substitution errors
   b. Initiation difficulty
   c. Variability of error pattern on repeated trials of the same word

(4) Difficulty hierarchy
   a. Vowel $<$ singleton consonants $<$ consonant clusters (though see below for errors related to vowels)
   b. The feature most vulnerable to errors is place of articulation
   c. Phonemic substitution is most common.
   d. Errors increase with increasing syllable length of utterance (higher probability or higher occurrence?)

(5) Aims
   a. Notions related to apraxia have been rather vague ("motor programming", "coordination")
   b. Hypothesis I: Utterances by apraxia patients are longer than normal speech?.
   c. Hypothesis II: Whether such lengthening effects arise from segmental or prosodic effects, or both.
   d. Hypothesis III: Other effects? Intensity? Prosody?
   e. Hypothesis IV: Whether acoustic properties match with intuitive description of apraxia.

TABLE 2. Sentence durations (in sec) for normal speakers (n = 10) and apraxic speakers 1–7.

The valuable watch was missing

Normal	*Apraxic*						
$\bar{x}$ = 2.24	1	2	3	4	5	6	7
SD = .28	6.0	7.6	15.2	3.2	3.2	15.2	6.8

In the summer they sell vegetables

Normal	*Apraxic*						
$\bar{x}$ = 2.12	1	2	3	4	5	6	7
SD = .27	5.6	8.8	18.0	3.6	2.8	7.6	6.0

The shipwreck washed up on the shore

Normal	*Apraxic*						
$\bar{x}$ = 2.4	1	2	3	4	5	6	7
SD = .33	4.0	8.0	16.0	3.2	4.0	12.8	–*

Please put the groceries in the refrigerator

Normal	*Apraxic*						
$\bar{x}$ = 2.0	1	2	3	4	5	6	7
SD = .25	8.2	12.8	15.2	4.8	5.6	8.0	8.4

*Not measured because of word-ordering errors.

Figure 1: Total duration.

2 Durational lengthening

(6) Lengthening

a. Overall, sentence durations are longer (Figure 1).

b. This lengthening is observed at the word level (Figure 2).

c. Panel b in Figure 2 shows lengthening at segmental level (articulatory prolongation).

d. Panel c in Figure 2 shows lengthening at syllable level, with pauses between each syllable (syllable segregation).

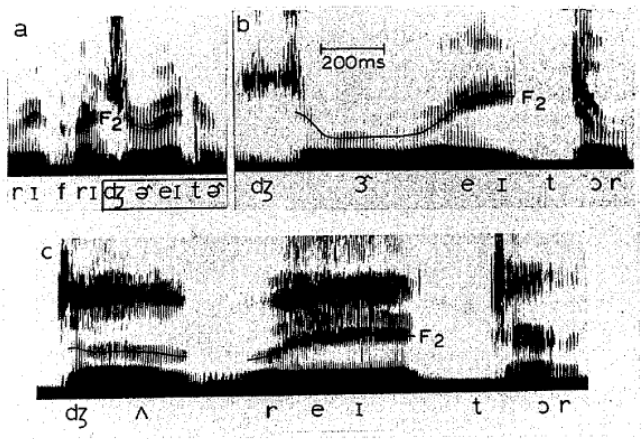

FIGURE 1. Spectrograms of the word *refrigerator* as spoken in sentence context by a normal speaker (a) and by two apraxic speakers (b and c). The pattern in (b) illustrates *articulatory prolongation* and the pattern in (c) illustrates *syllable segregation*. Unless noted otherwise, all spectrograms are conventional wide-band (300 Hz).

Figure 2: Lengthening.

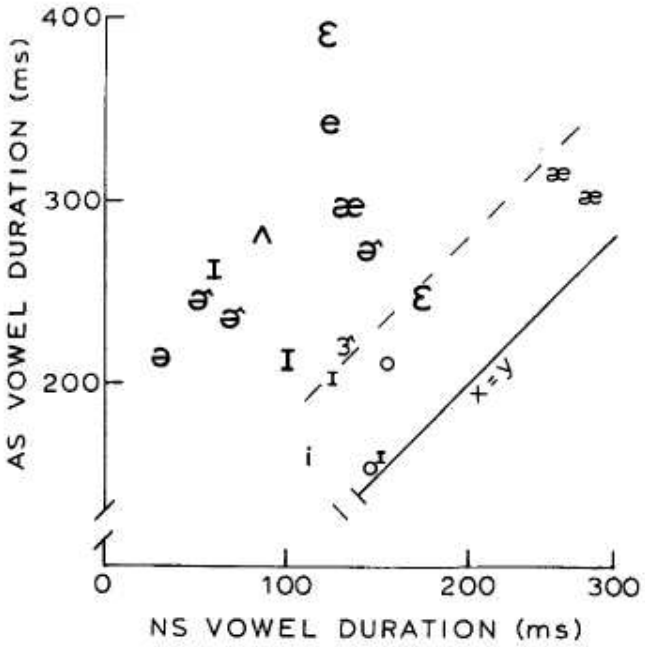

FIGURE 3. Vowel segment durations for apraxic speakers (AS) plotted against those for normal speakers (NS). Small phonetic symbols represent vowels in monosyllabic words, and large phonetic symbols represent vowels in longer words. The dashed diagonal nearly separates the apraxic data for the two symbol rises, indicating longer durations for vowels produced in the longer words.

Figure 3: A comparison of apraxia speech and normal speech: vowels.

(7) Lengthening at the segmental level: vowels

a. Figure 3 compares vocalic duration of apraxia speech and normal speech.

b. Large letters represent speech duration in long utterances; short letters represent monosyllabic pronunciations.

c. All symbols are above the diagonal axis; Large letters deviate more than small letters.

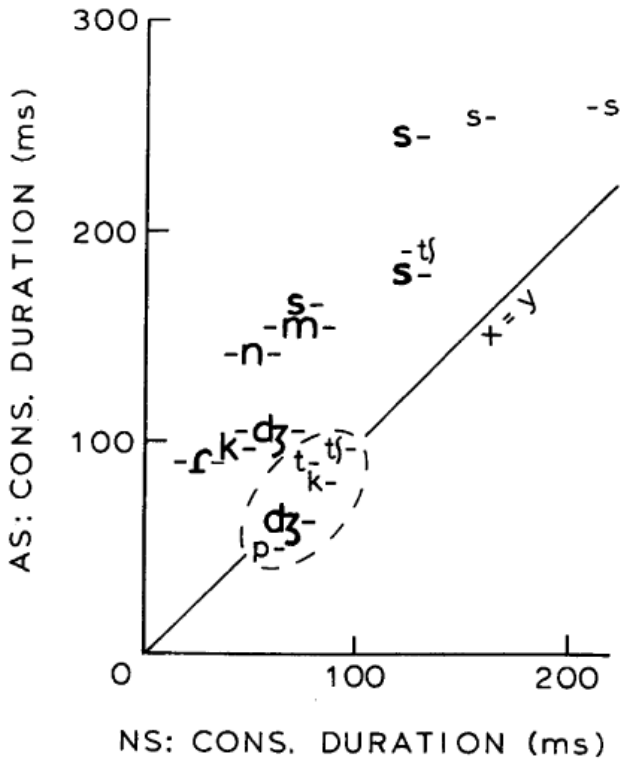

FIGURE 4. Consonant segment durations for apraxic speakers (AS) plotted against those for normal speakers (NS). Small phonetic symbols represent consonants in monosyllabic words, and large phonetic symbols represent consonants in longer words. Position of consonant in word is shown by positions of dashes; e.g., s- is word initial, -s- is word medial, and -s is word final. Dashed line encloses segment symbols for which no group difference emerges.

Figure 4: A comparison of apraxia speech and normal speech: consonants.

(8) Lengthening at the segmental level

a. Figure 4 compares consonantal duration of apraxia speech and normal speech.

b. Large letters represent speech duration in long utterances; short letters represent monosyllabic pronunciations.

c. "-" represents the presence of a segment; e.g. [s-] means "word-initial s".

d. All consonants except some word-initial obstruents show longer duration in apraxia speech.[1]

[1]I do not know how they measured durations of word-initial stops...maybe all the words were measured in sentences. Still, it would be hard to distinguish pause from voiceless stop closure.

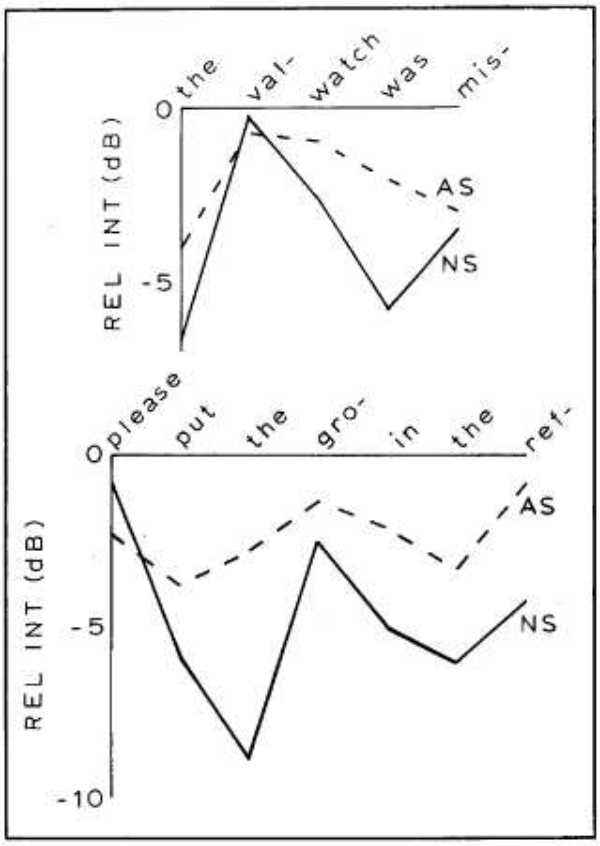

FIGURE 8. Relative peak intensities for words produced in two sentences by apraxic speakers (AS) and normal speakers (NS). Mean data are shown for each group. The sentences are *The valuable watch is missing* and *Please put the groceries in the refrigerator.*

Figure 5: Peak intensity contours, comparing apraxia speech and normal speech.

3 Intensity

(9) Intensity

a. A relativized intensity contour appears in Figure 5.

b. Peak intensity in each syllable is relativized with respect to the loudest syllable (note: explain why the values are all negative).

c. Apraxia speech shows a “flat” contour (e.g. *the*, which is usually highly reduced in normal speech, is almost as loud as the loudest sound in the sentence)

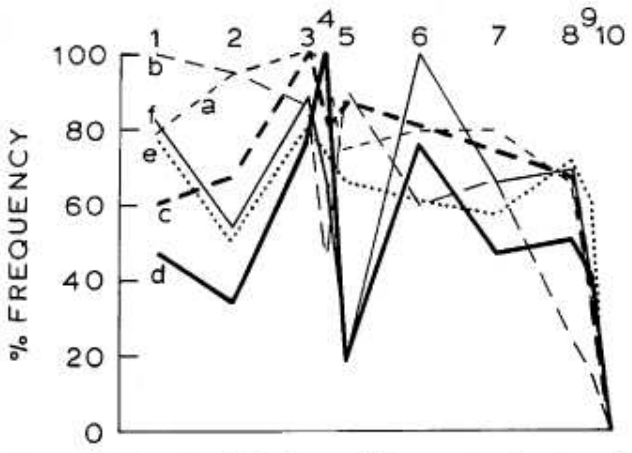

FIGURE 9. Normalized fundamental frequencies for selected time points in the sentence *They sell vegetables in the summer.* The letters represent apraxic speakers and their total sentence durations as follows (in order of increasing duration):

a) A2, 2.8 sec
b) A4, 3.6 sec
c) A1, 5.6 sec
d) A5, 7.6 sec
e) A6, 8.8 sec
f) A3, 18.0 sec.

The sampling points are (1) midpoint of diphthong /eɪ/; (2) midpoint of vowel /ɛ/; (3, 4, and 5) vowel midpoints for /ɛ/, /ə/, /ə/ in *vegetables;* (6) vowel midpoint for /t/; (7) vowel midpoint for /ə/; (8, 9, 10) vowel midpoint for /ʌ/, nasal murmur for /m/, and vowel midpoint for /ɚ/ in *summer.*

Figure 6: Intonation contours.

4 Intonation

(10) Intonation

a. Variable patterns across speakers.

b. No clear differences between apraxia speech and normal speech.

c. Sentence-final falls are consistently observed across speakers.

TABLE 4. Seriation or selection errors in apractic speech. The errors involve omissions, additions, or substitutions of phonetic segments.

Intended utterance		*Error production*
Orthographic	*Phonemic*	
dishes	/d ɪ ʃ ə z/	/d r ɪ ʃ ə z
jab	/d ʒ æ b/	/g æ b/
please	/p l i z/	/p r i z/
pleasingly	/p l i z i ŋ l ɪ/	/r i z i ŋ r ɪ/
Nebraska	/n ɛ b r æ s k ə/	/n ɛ b r æ s ə/
television	/t ɛ l ə v ɪ ʒ ə n/	/t ɛ l ə v ɪ z ə n/
several	/s ɛ v ɚ ə l/	/ʃ ɛ v r o/
tornado	/t ɔ r n e ɪ d o/	/t ɔ r n e o d o/
wreck	/r ɛ k/	/w ɛ k/
groceries	/g r o u ʃ ɚ i z/	/g o u ʃ ɚ i z/
twelve	/t w ɛ l v/	/t w ɛ l v z/
sixteen	/s ɪ k s t i n/	/s ɪ s t i n/
impossibility	/ɪ m p ɑ s ə b ɪ l ɪ t ɪ/	/ɪ m p ɑ s ə b u l t l ɪ/
washed up	/w ɔ ʃ t ʌ p/	/w ɔ ʃ ʌ p t/
shush	/ʃ ʌ ʃ/	/ʃ ʌ s/
judge	/d ʒ ʌ d ʒ/	/g d ʒ ʌ z/
vegetables	/v ɛ d ʒ t ə b ə l z/	/v ɛ d ʒ t ɚ b ɛ l z/
drinking	/d r ɪ ŋ k ɪ ŋ/	/d r ʌ ŋ k ɪ n/
vacation	/v e k e ɪ ʃ ə n/	/v e f e ɪ k ʃ ə n/

Figure 7: Segmental substitutions.

5 Segmental substitution

(11) Segmental substitution

a. Segmental substitution is common: addition, deletion, or substitution.

b. Figure 8 shows substitution of [l] with [r] (what's the acoustic cue that distinguishes [l] from [r]?).

c. Figure 9 shows various patterns of errors for the word *tornado*.

d. Panel B: voicing of the initial consonant.

e. Panel C: copying of the final vowel to the penultimate vowel.

f. Panel D: correct pronunciations, just lengthened.

g. For more complex cases, see Figure 10.

h. Panel A: A false start, consisting of several phonetic events.

i. Panel B: Mispronunciations of [zoo] (non-voicing, high F2 for back vowels)

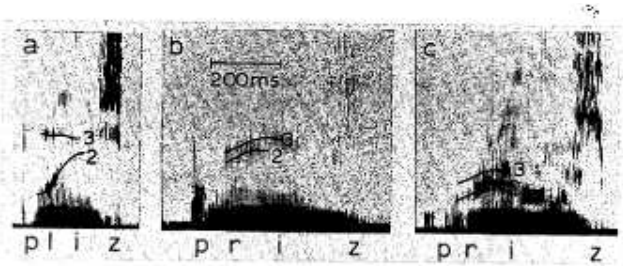

FIGURE 10. Spectrograms of the word *please* produced in sentence context by a normal speaker (a) and two apraxic speakers (b and c). The numerals identify the second and third formants. The apraxic utterances were perceived to be produced with r/l substitutions.

Figure 8: Replacing [l] with [r].

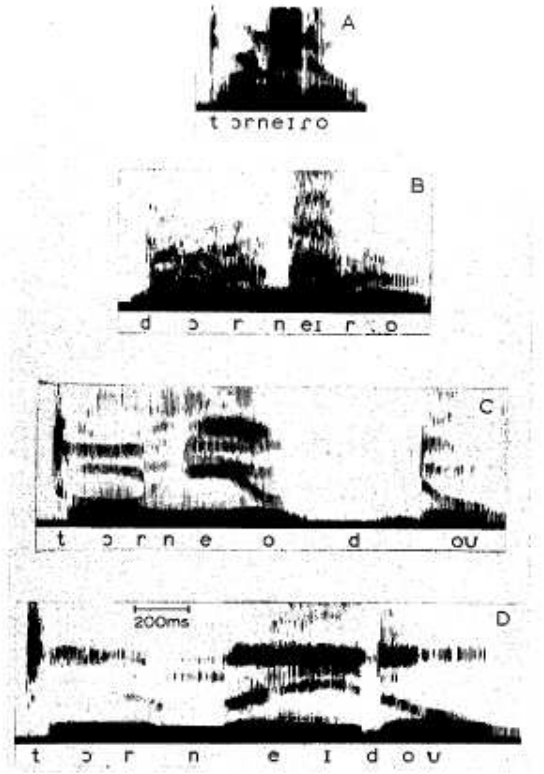

FIGURE 11. Spectrograms of the word *tornado* produced in isolation by a normal speaker (a) and by three apraxic speakers (b, c, d). The apraxic patterns illustrate a variety of errors of sequencing, timing, and coordination.

Figure 9: Segmental substitutions for the word “tornado”.

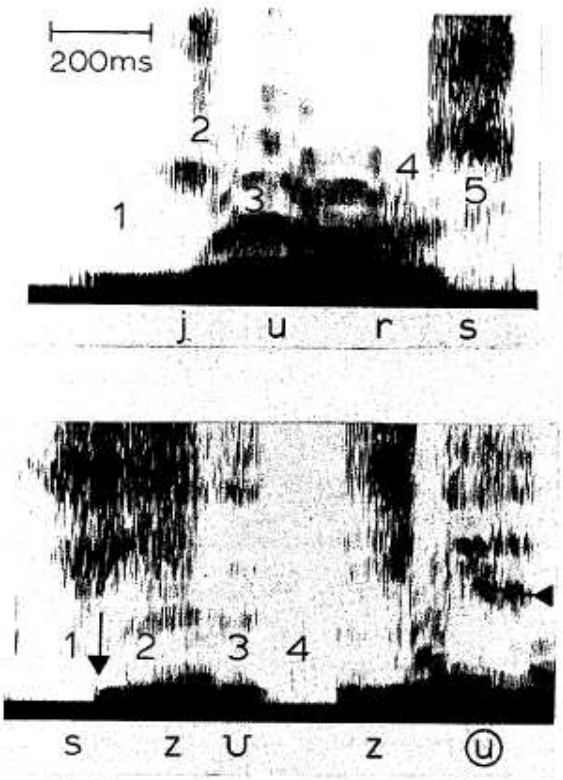

FIGURE 12. Shown in the upper spectrogram is a false start (initiation error) on the first syllable of the word *responsibility*. The numerals identify the following segments: 1) lengthy prevoiced interval, 2) glidelike initial phonetic segment, 3) prolonged vowel, 4) brief transition, and 5) final [s]. The lower spectrogram shows apraxic errors in the recitation of the monosyllable [zu]: 1) voiceless portion of initial fricative, 2) voiced portion of initial fricative, 3) brief vowel, 4) pause before a new attempt at the syllable is made. Line with arrowhead at extreme right indicates the second formant, which is inappropriately high in frequency for the intended vowel [u].

Figure 10: Complex errors for the words “responsibility” and “zoo”.

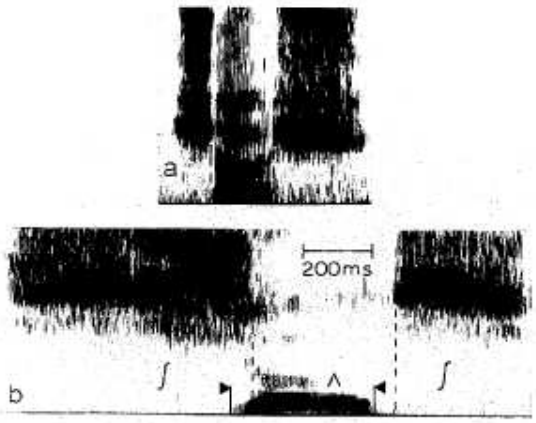

FIGURE 16. Normal (a) and apraxic (b) productions of the word *shush* [ʃ ʌ ʃ]. The solid and dashed lines in (b) show a timing or coordination error between the voiced segment for the vowel and the frication noise for the surrounding [ʃ] segments. (See text for explanations.)

Figure 11: Coordination error of voicing.

6 Subphonemic errors

(12) Subphonemic errors

a. Coordination error of voicing: Figure 11.

b. Diphthongization: Figure 12, Panel A.

c. Centralization (note the formant distributions)/neutralization: Figure 12, Panel B.

d. Vowel space illustrated in Figure 13; seems “normal”

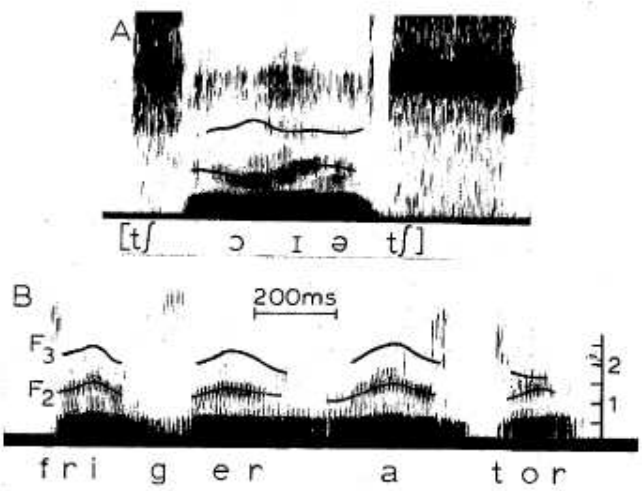

FIGURE 17. Vowel errors in apraxic productions of the words *church* (a) and *refrigerator* (b). (See text for discussion of formant patterns.)

Figure 12: Dipthongization (Panel A) and centralization/neutralization (Panel B).

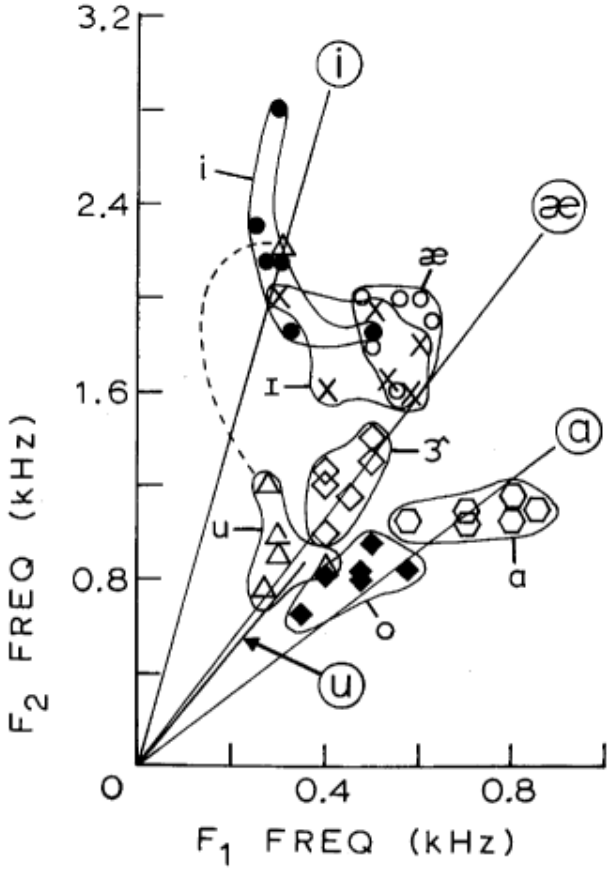

FIGURE 18. Vowels of six apraxic subjects shown in F_1-F_2 plot with isovowel lines for normal productions of [i u a æ].

Figure 13: Vowel space.

7 Summary

(13) Summary: characteristics of apraxia speech (p. 242-243)

a. slow speaking rate with prolongations of transitions and steady states as well as inter-syllable pauses
b. restricted variation in relative peak intensity across syllables
c. slow and inaccurate movements of the articulators to spatial targets for both consonants and vowels
d. frequent mistiming or dyscoordination of voicing with other articulators
e. occasional errors of segmental selection or sequencing including intrusion, metathesis, and omission
f. initiation difficulties often characterized by false starts and restarts
g. complex sound sequences associated with prolongations, interruptions, and inappropriate phonetic variations.

References

Kent, R. D., & Rosenbeck, J. C. (1983). Acoustic patterns of apraxia of speech. *Journal of Speech and Hearing Research, 26*, 231-249.