Evidence for a Motor Performance Deficit Versus a Misapplied Rule System in the Temporal Organization of Utterances in Apraxia of Speech

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Temporal discoordination of articulatory movements, slow rate, and abnormal or unusual prosodic patterns are often reported for persons with apraxia of speech. These auditory perceptual observations have led investigators to examine more specifically the acoustic manifestations of these difficulties. Many of these studies have illustrated slower rate and lengthened segment durations for apraxic speakers (Collins, Rosenbek and Wertz 1983; Kent and Rosenbek, 1983; Mercaitis, 1983). Kent and Rosenbek (1983) reported that apraxic speakers have slower than normal speaking rates and they presented evidence that apraxic speakers differ in the sequential orderin of phonemes as well as in the processes of moving from one phoneme to another. They attributed the slower rate to either articulatory prolongation, which they described as lengthening of the steady state segments and the intervening transitions, or syllable segregation, which they defined as the intervals between lengthened syllables.

Another interesting finding has been that apraxic speakers exhibit relative segment durations across varied response requirements that are similar to those in normal subjects, although absolute values are usually greater. Collins, Rosenbek and Wertz (1983) reported changes in vowel duration which occurred with changes in word length. Mean vowel and word durations were reported for three sets of words (please, jab and zip) which varied in length from one to three syllables (i.e. zip, zipper, zippering). Absolute word and vowel durations were longer for the apraxic subjects. Both groups, however, responded with shorter vowel durations as the words increased in length. When durational differences were controlled by computing the ratios of word duration to vowel duration the two groups performed similarly. The authors proposed that "the similarities of these ratios, despite the longer durations for the apraxia of speech group, suggests differences in neuromuscular positioning for articulatory sequences rather than difficulties at a phonological level" (pg. 228). This suggestion that apraxic speakers follow similar "rules" for the changes in the organization of temporal factors in utterance production leads to further questions regarding changes in the execution of temporal motor plans over a variety of response requirements. It is of interest to ask if other temporal measures, such as interword interval, would also result in "rule" similarities between apraxic and normal speakers even though the absolute values would be expected to differ.

The data presented in this paper were collected in the context of a larger study designed to compare apraxic and normal speakers on a variety of acoustic measures during production of words, word strings and sentences of varying length. The purpose of this particular study was to determine if lawful relationships in interword interval occurred for both apraxic and normal subjects when the response requirements (two word string conditions and three sentence conditions) differed. Differences between groups in absolute values, along with similarities between groups in changes in duration across conditions, would suggest that the primary deficit in apraxia of speech is one of activation or execution of temporal plans that follow rules similar to those for normal speakers.

METHOD

Five adults exhibiting acquired apraxia of speech and five adults with no history of neurologic disorder served as subjects. Specific criteria were delineated for inclusion in the apraxia of speech group. These included 1) the presence of effortful trial and error groping, dysprosody, error inconsistency, difficulty in initiation, and substitution and distortion errors; 2) articulatory agility, phrase length and melodic line ratings between 1 and 4 on the Boston Diagnostic Aphasic Examination (Goodglass and Kaplan, 1983) rating scale profile of speech characteristics; 3) fewer segmental and prosodic errors exhibited during repetition of sentences taken from their own verbal description of the "cookie thief" picture than in their spontaneous speech; 4) absence of dysarthria as judged perceptually by criteria established by Darley, Aaronson and Brown (1975). Coexisting aphasia was allowed, but subjects had to perform at or above the 50th percentile for aphasic persons on the 5-item Revised Token Test (McNeil and Prescott, 1978; Arvedsen, McNeil and West, 1985); and exhibit grammatical form and paraphasia ratings between 5 and 7 on the BDAE rating scale.

One female and four male apraxic subjects participated in this study after meeting all inclusion criteria. One female and four male subjects comprised the control group. They achieved scores within the normal range on the two-item version of the Porch Index of Communicative Ability (DiSimoni, Keith, Hold and Darley, 1975) and on the selected subtests of the BDAE and were judged by two speech pathologists to exhibit normal speech and language skills. Descriptive information about subjects is presented in Table 1.

Stimuli were constructed for three specific tasks -- words, word strings, and sentences. Both /u/ and /ei/ vowel contexts were used for analyses in order to build a replication within the design (Table 2). A third set of similarly constructed sentences (I keep fit; I keep fit working; I keep fit working in the gym) was included to decrease adaptation effects but was not measured.

Careful consideration was given to those factors reported in the literature to influence phonetic durations in word and sentence production. The sentences were constructed to control for intonational contour and position of target words. Each stimulus item was prerecorded to ensure equal presentation rate, intensity, stress and intonational contour. A stimulus tape, consisting of eleven randomized repetitions of each prerecorded stimulus item, was created for presentation to the subjects. A 500 ms., 1500 Hz tone, designed to be the signal for the subject to produce the utterance, was inserted 1000 ms. after the stimulus utterance for ten of the eleven items in each condition. The tone was omitted for one stimulus item in each condition in order to provide catch trials to discourage subjects from anticipating the signal to produce the utterance.

Each subject was seen for one experimental session. Subjects were told that they would hear a series of utterances which would be either a word, a string of words or a sentence. They were to wait for the tone to tell them when to speak, and then repeat the utterance following the tone. Stimuli were presented in a sound field via audio cassette at a comfortable hearing level. Each speech sample was recorded in a quiet environment with high quality recording equipment. A head mounted microphone allowed for a consistent 12 cm mouth-to-microphone distance.

Table 1. Descriptive data and test results for the five apraxic and five normal subjects.

Subject	Age	Sex	Years Post CVA	PICA	RTT	Boston
A1	47	M	16	13.6	13.1	45
A2	44	F	3	14.6	13.5	45
A3	49	M	5	13.8	13.4	49
A4	61	M	6	13.8	14.4	45
A5	72	M	3	13.6	13.2	42
N1	42	M		14.6	14.9	60
N2	56	M		15.0	13.2	60
N3	57	F		13.8	14.9	60
N4	72	M		14.4	15.0	60
N5	54	M		15.0	12.4	60

Site of Lesion	Severity
A1 left frontal cerebral hemorrhage	moderate
A2 left middle cerebral artery occulsion	mild-moderate
A3 left hemisphere embolic CVA	moderate
A4 left middle cerebral artery - embolic	moderate
A5 left middle cerebral artery - embolic	moderate/severe

Table 2. Word, word string, and sentence stimuli.

COOK STIMULI SET

Cook
Cooker
Cookery
Cook cook cook
Cook cook cook cook cook
I cook stew
I cook stew slowly
I cook stew slowly in a pot

TAPE STIMULI SET

Tape
Taper
Tapering
Tape tape tape
Tape tape tape tape tape
I tape shows
I tape shows often
I tape shows often in my home

Acoustic analysis of each subject's tape recorded utterances were derived from wide band (300 HZ) spectrograms which were made on a Kay Digital Sonagraph (Model 7800). The interword intervals were measured by hand to the nearest millimeter from the spectrogram and then translated to milliseconds.

The first interword interval (IWI 1) was measured from the final pulse of periodic vocal fold vibration in the first word (of either the word string or the sentence) to the aspiration burst or onset of frication in the second word of the utterance. The second interword interval (IWI 2) was measured from the final pulse of periodic vocal fold vibration in the second word of the word string or sentence to the aspiration burst or onset of frication in the third word of the utterance.

RESULTS

A two way (group by condition) repeated measures ANOVA was used to compare the differences between the apraxic and normal groups as well as to compare the duration differences in interword intervals among the two word string and three sentence conditions. Separate ANOVAs were computed for each vowel context for IWI 1 and IWI 2.

Both the first and second interword interval durations were consistently longer for the apraxic subjects than for the normal subjects. This was true for every subject and was seen in both sets of stimuli.

Figure 1 illustrates the apraxic and normal group mean durations for IWI 1 for the "cook" stimuli. The apraxic group exhibited significantly longer durations than the normal group ($F(1,32) = 35.52$; $p < .05$). A significant difference was also found for condition ($F(1,32) = 20.10$; $p < .05$). Post-hoc Scheffe tests suggested that there were differences between each word string versus sentence comparison. These differences were characterized by reductions in interword interval duration for sentences versus word strings. The normal subjects decreased the first interword interval in sentences compared to word strings by 48%. The apraxic subjects also reduced interval durations, but to a lesser extent, by 33%.

Figure 2 illustrates the apraxic and normal group mean durations for IWI 1 for the "tape" stimuli. A significant difference was found between groups ($F(1,32) = 14.64$; $p < .05$), and condition ($F(1,32) = 4.27$; $p < .05$). Again, the apraxic speakers exhibited significantly longer interword intervals, with a similar reduction in interval durations in the sentence stimuli. In this context, the normal subjects reduced intervals by 51% while the apraxic speakers reduced them by 10%.

The same pattern of results was shown for the second interword interval, although not as consistently. Figure 3 illustrates the apraxic and normal group mean durations for the "cook" stimuli. Again the apraxic group exhibited significantly longer mean interword intervals ($F(1,32) = 19.79$; $p < .05$). The condition comparison was also significant ($F(1,32) = 3.15$; $p < .05$). In this case, the normal group decreased interword interval durations by 60%, but the apraxic group decreased these intervals by only 1%. Examination of individual subject data, however, revealed that most second IWI mean durations were decreased in sentence stimuli. Apraxic Subject 5 exhibited large increases in interword intervals for all three sentences, increasing the group mean.

Figure 4 depicts the mean IWI 2 durations for the "tape" stimuli. A significant main effect was found for group ($F(1,32) = 11.84$; $p < .05$. The apraxic speakers again exhibited longer mean durations. In this vowel context, the normal speakers reduced interword interval durations in sentences by 78% while the apraxic group again exhibited only a 1% decrease. Similar to the

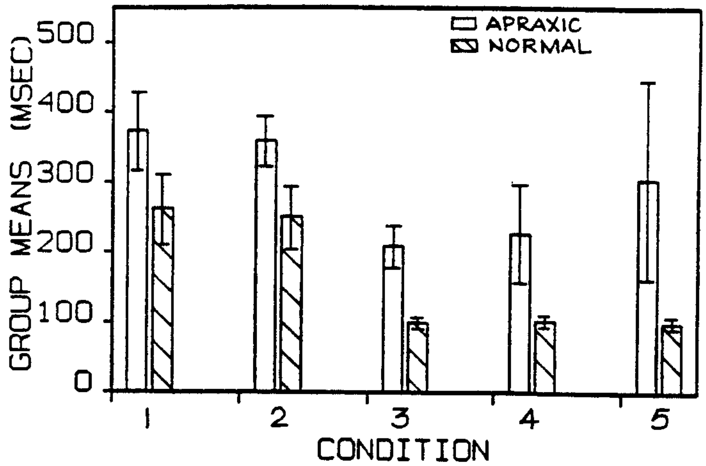

Figure 1. Apraxic and normal group mean durations for IWI 1 for: 1) cook, cook, cook; 2) cook, cook, cook, cook, cook; 3) I cook stew; 4) I cook stew slowly; 5) I cook stew slowly in a pot.

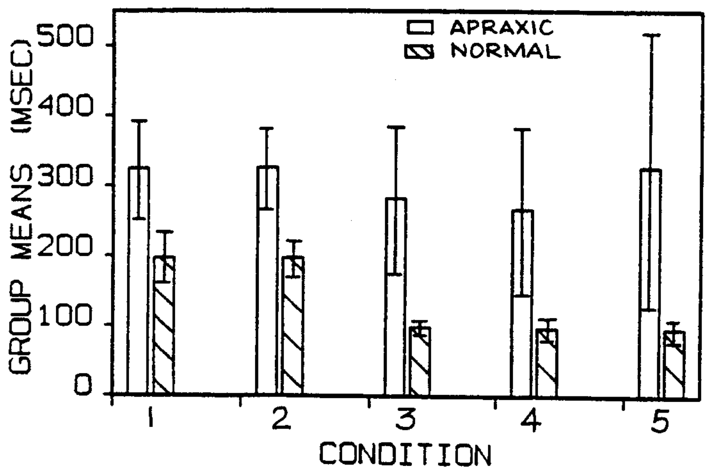

Figure 2. Apraxic and normal group mean durations for IWI 1 for: 1) tape, tape, tape; 2) tape, tape, tape, tape, tape; 3) I tape shows often; 4) I tape shows often in my home.

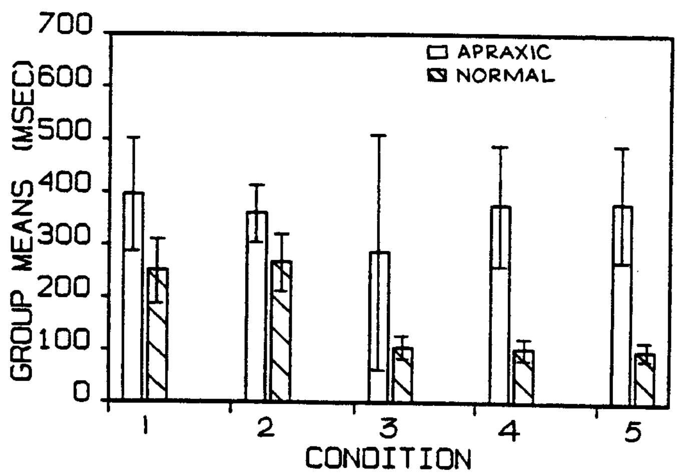

Figure 3. Apraxic and normal group mean durations for IWI 2 for: 1) cook, cook, cook; 2) cook, cook, cook, cook, cook; 3) I cook stew; 4) I cook stew slowly; 5) I cook stew slowly in a pot.

results reported for the "cook" stimuli, three of the five apraxic subjects decreased mean IWI 2 intervals in the sentences. Apraxic subjects 4 and 5 exhibited increases for the sentence stimuli, especially for the longer sentences.

In order to examine more specifically intrasubject and intersubject variability, the coefficient of variation (CV) was computed and plotted for each subject. The CV is derived by dividing the sample standard deviation by the sample mean.

Figure 5 illustrates the CV plotted with the mean for each of the 10 subjects for IWI 1 for the "cook cook cook" word string. In the word string stimuli, while the apraxic speakers exhibited greater absolute values, the intersubject and intrasubject variability was similar for both groups. In the sentence stimuli, however, the intersubject and intrasubject variability was much greater for the apraxic speakers than the normal speakers (Figure 6). While both groups exhibited reductions in absolute values, the normal group exhibited greater homogeneity. This was true for every condition in both vowel contexts for both IWI 1 and IWI 2.

DISCUSSION

The interword interval data reported here provide additional descriptions of the temporal execution of motor programs in utterance production for apraxic and normal speakers. The results of this study support previously reported evidence that apraxic speakers consistently exhibit increased inter-segmental durations in utterance production (Kent and Rosenbek, 1983). Further, the comparison of changes in temporal measures across varying response requirements facilitates inferences regarding the nature of these increased durations. These data support earlier suggestions that apraxic speakers may follow similar "rules" for the temporal organization of utterances to those followed by normal speakers, even though the absolute magnitude of durational measures is consistently greater (Collins, Rosenbek and Wertz, 1983).

The results for IWI 2 were not as consistent across subjects as were those for IWI 1. It is important to note that there is a word final and a word initial articulatory gesture included in this measure, which increases articulatory complexity. A second explanation applies specifically to apraxic subject 5 who tended to have particular difficulty with most sibilant sounds. He frequently exhibited marked groping in an effort to reach /s/ and /ʃ/ in the units measured.

The fact that most of the apraxic subjects demonstrated reduced IWI durations in sentence conditions compared to word string conditions as normal subjects did, provides evidence that the apraxic speakers may follow the same "rules" for changes in the organization of temporal factors in sentence production. However, they do so with less consistency and precision. The tendency for apraxic subjects to reduce interword intervals, although to a different magnitude than normal subjects, argues for an impaired precision mechanism in activating and executing motor plans. This explanation is in contrast to one of a misapplied rule system.

With the increasing body of temporal acoustic descriptions of apraxic utterances, the question arises as to whether it may be of value for clinicians to focus attention on the potential use of these measures as dependent variables in clinical designs for treatment. For example, how useful might these temporal measures be as indicators of change? It might be argued that only those changes that are perceptually observable and add to the increased intelligibility or acceptability of the patient's speech are

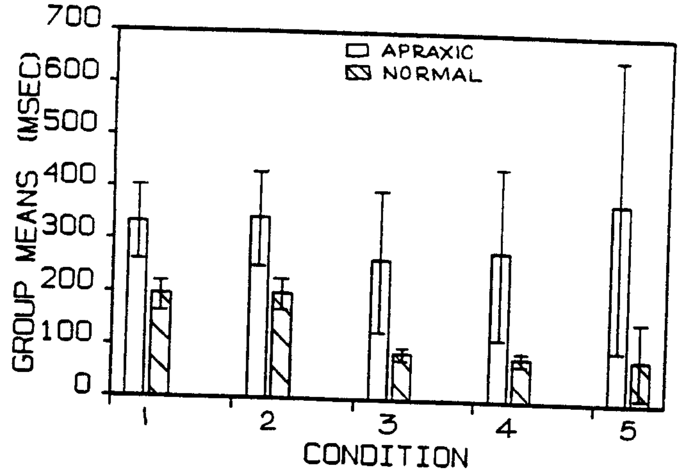

Figure 4. Apraxic and normal group mean durations for IWI 2 for: 1) tape, tape, tape; 2) tape, tape, tape, tape, tape; 3) I tape shows; 4) I tape show often; 5) I tape shows often in my home.

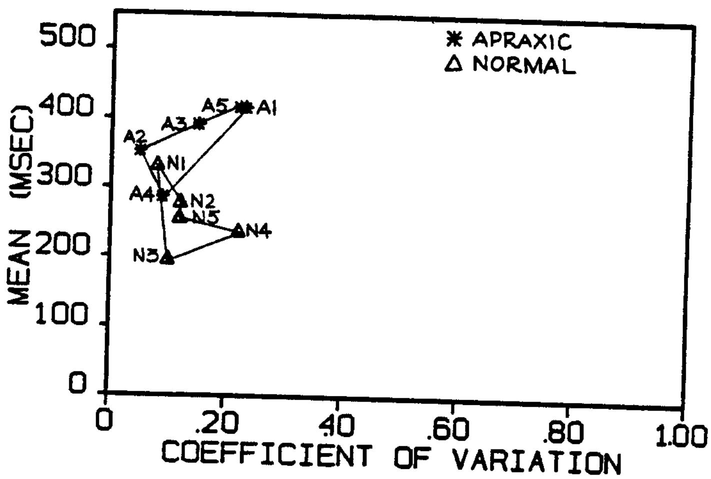

Figure 5. Coefficient of varia plotted against the mean IWI 1 duration for each subject for "cook, cook, cook."

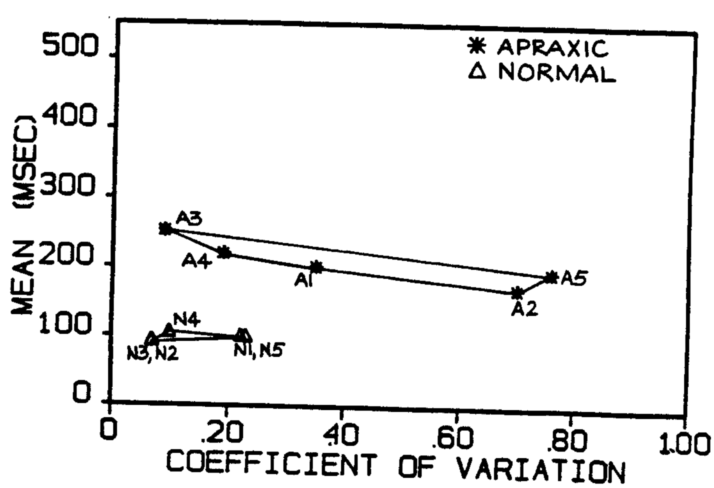

Figure 6. Coefficient of variat plotted against the mean IWI 1 duration for each subject for "I cook stew."

important as indicators of the effects of treatment. In that case, acoustic descriptions such as these may have more theoretical value. In either case, further insight into the nature of apraxia of speech might be facilitated by using acoustic data to generate questions for study in both group and single subject designs.

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DISCUSSION

Q: Why should a group of clinical aphasiologists care about these kinds of designs and these kinds of results?

A: I believe it's extremely important for working clinicians to have not only a thorough understanding of the literature that discusses theoretical issues, but to work toward developing our own theoretical models about what's going on with our patients. It's very important to me to be working toward developing my own models, both of apraxia of speech, and of utterance production. Data such as those reported in this acoustic study, and in physiological studies such as that reported by Monica this morning are important information to include in the development of our own theoretical models into which we can then fit our clinical decisions. Hopefully over the course of our career, our models and subsequently our clinical decisions will change.

I might be a little more specific by saying that one can also use acoustic data such as these to generate more specific questions for study. In the paper, I suggested that this was true for group designs, but I think it might also be true in our single subject designs. I'm not sure at this point if I would use temporal acoustic data to determine temporal targets for change. That is, at this point I wouldn't choose a temporal measure as a dependent variable in a design. At this time, I prefer to target the more perceptual phenomena that actually contribute to the intelligibility or the acceptability of the patient's speech. However, I think that, by looking at acoustic data we might be able to make better clinical decisions regarding, say, stimuli, or heirarchical targets, for example, because these data aid the development of our own theoretical models about what is going on with our patients.

Q: Did you analyze the stimuli that you presented acoustically?

A: We taped the stimuli to assure that equal temporal factors, rate, intensity, etc. would be presented to each subject. This was in an effort to control for any effects stimuli might have on the temporal factors of the subjects' responses. We did not acoustically analyze the stimuli.

Q: Perceptually, how noticible were the differences in duration in the apraxic speakers? Were they real noticeable in comparison to the normal speakers? Also, was a rate variable included in the criteria for subject selection?

A: The criteria did not specify any requirements concerning rate. The criteria were rather specific in order to get subjects who were apraxic and yet had minimal aphasia. There was no specification regarding rate or pause symptomatology other than those behaviors characteristic of apraxic speech, such as difficulty with initiation.

With respect to your question regarding perceptual observations, I did phonetically transcribe each utterance at the time I measured the spectrogram. I had intended to compare the temporal measures of those utterances which contained articulatory errors with those that did not. As it turned out, there were not enough substitution or distortion errors to warrant that analysis. This was surprising due to the moderate to severe apraxia exhibited by most of the subjects and may have been due to the nature of this very repetitive task.

Q: Perceptually, I'm wondering how different the apraxic subjects were in spontaneous speech compared to their responses in the repetition task.

A: While fewer substitution and distortion errors occurred in the repetition task, the other characteristics of their speech, such as rate, hesitations, false starts, and other prosodic factors were perceptually very similar in repetition and in spontaneous speech. I also measured vowel durations, which I did not report today. While the vowel durations were significantly longer for the apraxic subjects in every response type, they were not perceptually different, to my ear, than those produced by the normal subjects. The interword intervals, however, did perceptually seem to be greater than those exhibited by the normal subjects, so there is a little disparity with regard to how perceptually evident these acoustic differences are.

Q: What type of aphasia did these patients have, since you state they all had some coexisting aphasia and you had BDAE data?

A: Each of these apraxic subjects exhibited only a very mild aphasia. Only portions of the BDAE were administered as part of the descriptive test battery. We chose to thoroughly describe the speech and language behaviors of these subjects, but did not classify them according to type of aphasia.

Q: Have any of these subjects been treated?
A: Yes, they had all received a course of treatment. None were in treatment at the time of data collection.

Q: Is there any possibility that the type of treatment had any influence on these data?
A: I wondered about the possible effects of prior treatment. Given the consistency of the results across all five subjects who had varying lengths of treatment, my guess is no. However, depending on the type of intervention a clinician uses with patients, I believe treatment could have an effect on this type of data.

Q: Given the relative absence of substitution and distortion errors, how typical do you think your subjects are of all apraxic patients?
A: They were quite typical except that they did not have the degree of coexisting aphasia that most patients we see -- at least those I see in my practice -- have. In their spontaneous speech, substitution and distortion errors were much more frequent than in the repetition task. Hesitancy, difficulty in initiation, groping, and dysprosody were frequent in both spontaneous speech and repetition. The well-practiced repetition task probably resulted in the decrease in substitution errors noted in the apraxic subjects' responses.

Q: If I remember your subject slide correctly, your subjects were all a good time post onset. Are you at all concerned that what you are seeing is a reflection of compensations that these people are making for their deficit as much as it is characteristic of their primary deficit?
A: That's an excellent question, and one which I've thought a lot about. The issues relating to "compensatory" versus "primary deficit" characteristics of apraxia of speech are complex and difficult to address in well-controlled studies. I think it matters a lot to us clinically to be concerned about such a differentiation. Coming to some carefully thought out model, based on carefully collected data has to take into account the role of compensatory behaviors. While I don't think we as a group have come to any universally accepted conclusions, it's important that we continue to consider the issue not only in our research designs, but also in our clinical decisions. Clinically, one has to consider this issue in every decision, from what we present to these patients as stimuli, to the hierarchy of progression of stimuli, to how we're going to progress in the course of treatment, and finally, to how we're going to measure change.

Q: You used 5 and above on grammatical form and paraphasias as a selection criterion. Now the latter is tough, because you have to say those articulatory things I hear are not paraphasias. So, what were the things you were throwing out in the areas of paraphasias?
A: Because of some of the inconsistencies in the data reported in the area of apraxia of speech, I wanted to describe the behavior of the subjects well so that when I discussed the data at least people would know what kind of subjects I worked with. I was worried about the problem of trying to decide just how much aphasia existed along with their apraxia. As it turned out, the substitution errors exhibited by these subjects, accompanied by groping and dysprosody, were not characteristic of the literal and verbal paraphasias I associate with aphasic patients.

Q: Were these folks agrammatic, and would that have any influence on the temporal results that you found?

A: They were not agrammatic. I believe if they were, it could have some effect on these measures, especially on the interword interval durations, if they were searching for grammatical form, or trying to be grammatical.