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PHONETIC CHARACTERISTICS OF DYSARTHRIA

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Introduction

Much of the literature on dysarthria and dysarthric speech is characterized by the absence of empirical data. Conclusions by a wide range of investigators concerning the relation of the dysarthrics' speech to locus and type of lesion producing the symptoms have been based on gross clinical evaluations of the speech signals. The neurological literature has been equally imprecise with respect to several important parameters which are necessary in order that accurate localization can be achieved. Analysis of the speech has been equally gross, with few operational definitions of either the speech patterns or the term used to indicate the degree of speech impairment.

The basic objectives of the research being presented in this report were to determine the possibility of providing better descriptions of dysarthric speech. Two points of view were surveyed. On the one hand, we sought to describe the acoustic-phonetic characteristics of this speech impairment by employing analytic procedures common to experimental phonetics and speech science. Our second basic purpose was to attempt to devise methods by which the degree of speech

impairment in dysarthria could be quantitatively and objectively evaluated.

It was our hope that data obtained from such approaches might correlate with each other, and with clinical information relating the neurological basis of the speech problems as well as the assessment of dysarthria as determined by speech therapists. While this was not the major goal of the research program, it was always prominent in our evaluation and description of the experiments and their subsequent interpretation. Another, and perhaps less overt objective, was to demonstrate that the techniques of experimental phonetics and intelligibility testing could make an important contribution to the clinician and open the way for others to apply the procedures employed in research in other types of speech impairments.

Some of the particular expectations and objectives of the research program, such as spectrographic analysis of sentence utterances, analysis of supersegmental features, measures of phonation and respiration during speech and a scale to assess intelligibility, were not achieved. But the major purposes were accomplished. The results obtained from the research that was carried out did fulfill our basic goals.

The five major objectives of the research program were:

1. To provide a detailed description of the acoustic-phonetic characteristics of the speech
2. To compare spectrographic data obtained from dysarthrics to data from normal speakers;
3. To compare the acoustic characteristics of the steady state of vowels contained in words recorded by dysarthric and normal speakers;
4. To compare the intelligibility of dysarthric and normal speech by means of listener responses to words and sentences recorded by both groups of speakers;
5. To examine the power of the words used to discriminate among dysarthrics as a means of estimating the range of reduction in intelligibility.

Methods of Procedure

As was described above, two approaches to the systematic study of dysarthric speech were employed in this research. One approach was acoustic-phonetic and the other the assessment of intelligibility.

However, materials and speakers were identical in the first series of experiments. This provided an appropriate means by which to examine the relations between acoustic-phonetic and intelligibility measures derived from the same sources. A second group of dysarthric speakers was used to yield data on revised measures of intelligibility. The "new" materials for assessing intelligibility were derived from the original set of data. Results of the studies will be described in the following section.

This section describes the materials, subjects, equipment and general approach used to obtain the data discussed in the results section.

Material Recorded by Speakers: In the initial series of studies speakers recorded 160 words and 40 brief sentences. Tests words were organized into three lists: 50 monosyllabic CNC (Consonant-Syllable Nucleus-Consonant) words; 60 Cluster (to be described below) words and 50 Spondee words.

The CNC words used contained an initial consonant phoneme, one of the 15 stressed syllable nuclei of American English, and a final consonant phoneme. Words of this type have been shown to be useful in the study of speech intelligibility.¹ The 50 words used for the acoustic-phonetic analysis and the initial intelligibility studies were taken from the lists of CNC words compiled by G.E. Peterson and I. Lehiste. Table 1 presents the 50 CNC words.

The 60 cluster words (Table 2) were compiled specifically for this study. These monosyllabic words have initial and/or final consonant clusters. Although not all possible consonantal clusters of American English are contained in the list, the most frequent ones are represented. Consonantal clusters were used to permit an evaluation of the dysarthrics' ability to make rapid articulatory and phonatory shifts.

The 50 Spondee words (Table 3) were selected randomly from lists I and II of Auditory Test No. 9 of the Psycho-Acoustic Laboratory, Harvard University.² Spondees provided a sample of dysarthric speech with polysyllabic words.

¹"Linguistic considerations in the study of speech intelligibility" by I. Lehiste and G.E. Peterson, J. acoust. Soc. Amer. 31: 280-286 (1959); "Revised CNC lists for auditory tests" by G.E. Peterson and I. Lehiste, J. Speech Hearing Disorders 27: 62-70 (1962).

²C.V. Hudgins et al.: "The development of recorded auditory tests for measuring hearing loss for speech". Laryngoscope 57: 57-89 (1947).

Table 1. CNC Words

kid	well	perch
rig	mate	sung
noise	work	head
gull	pod	man
shine	with	soon
dirge	bush	bell
rat	house	jail
four	toll	numb
dab	faith	chin
dip	sheep	life
tone	toss	
room	bar	
lake	pike	
fade	more	
leave	vote	
hut	piece	
gap	what	
keg	size	
keen	rouge	
yam	joke	

Table 2. Cluster Words

wasp	text	strife
bronze	sketch	dwarf
twist	arch	crown
left	showered	part
forth	shrug	purse
sleeps	fraud	tongue
planned	charge	clears
speaks	gloss	drop
range	train	smiled
field	bangs	dark
cats	thread	harp
hums	champ	switched
tests	barb	chant
bolt	queens	sprig
built	scrub	flowers
grove	bounce	fused
schools	pinch	blush
spice	shank	sledge
sticks	else	bind
pride	pact	cute

Table 3. Spondee Words

bagpipe	cupcake	workshop
footstool	backbone	lifeboat
scarecrow	sundown	birthday
housework	oatmeal	eardrum
pinball	hedgehog	playground
mushroom	northwest	drawbridge
yardstick	schoolboy	buckwheat
duckpond	hardware	starlight
inkwell	pancake	armchair
doorstep	coughdrop	platform
whitewash	blackboard	
toothbrush	watchword	
airplane	woodchuck	
daybreak	headlight	
hotdog	wildcat	
horseshoe	woodwork	
cookbook	nutmeg	
shipwreck	padlock	
outside	eggplant	
washboard	earthquake	

Tables 4,5, 6 present the tabulations of the occurrence of some of the important phonetic characteristics of the test words. Table 4 gives the distribution of syllable nuclei among the lists. Table 5 gives the frequency of occurrence of each consonant in the initial position and as a member of an initial cluster, and similar information for consonants in the final margin is given in Table 6.

Forty sentences were constructed to sample dysarthric speech beyond the single word utterance. The sentences recorded by the speakers is given in Table 7.

All of the acoustic-phonetic analysis was carried out on the three word lists described above. In addition, recordings of these words were employed to evaluate the intelligibility of dysarthric speech. The forty sentences were also used for intelligibility analysis. Results of the initial intelligibility studies were employed to reduce the test list from 160 to 50 words. This new list (Table 8) was derived from an item analysis of listener responses to the original 160 words. The revised list contains 6 CNC's, 24 Clusters and 20 Spondees. A new sample of dysarthrics recorded these words for a follow-up study of intelligibility.

Subjects. Ten dysarthrics (male) obtained through the cooperation of the Speech Clinic, Department of Neurology,

Table 4. Occurrence of Syllable Nuclei in the Test Words

Syllable Nucleus	CNC words	Cluster words	Spondee Words		Total
			First component	Second component	
i	4	4		2	10
ɪ	5	7	4	2	18
eɪ	5	2	2	6	15
ɛ	4	7	5	7	23
æ	5	7	6	2	20
	4	5	6	3	18
ɑ	3	9	6	4	22
ɔ	3	4	6	7	20
ou	4	2	1	3	10
u	1		4	1	6
u	3	3	2	3	11
r	3	1	3	3	10
au	1	4	2	2	9
aɪ	4	5	3	4	16
ɔɪ	1			1	2
	50	60	50	50	210

Table 5

Occurrence of Consonant Phonemes
in the Initial Margin

Phoneme	Word-initial		In first position in initial cluster		In second position in initial cluster		In third position in initial cluster		Total in initial margin
	Utter- ance initial	Post- junc- tural	Utter- ance- initial	Post- junc- tural	Utter- ance- initial	Post- junc- tural	Utter- ance- initial	Post- junc- tural	
b	13	7	2	3					25
d	7	3	3	2					15
g	2		2						4
p	11	2	2	2					17
t	7		2			3			12
k	7	3	2	2	5				21
j	2		4						2
c	4	2							6
v	1								1
f	6	1	3						10
s	4	1	15	3					23
ʃ	5	2	1						8
h	11	1							12
m	4	2			1				7
n	4								4
l	5	3			10				20
r	5	2			10		3		25
w	10	7			4				22
W	2	1							3
y	2				2				4
#	10								10

Table 6

Occurrence of Consonant Phonemes in the Final Margin

Phoneme	Word-final		In first position in final cluster		In second position in final cluster		In third position in final cluster		Total in final margin
	Utter- ance final	Pre- junc- tural	Utter- ance final	Pre- junc- tural	Utter- ance final	Pre- junc- tural	Utter- ance final	Pre- junc- tural	
b	2	4			1		1	3	3
d	9	2			7		7	23	23
g	7	2						9	9
p	8	2	1		3			14	14
t	11	6	1		11			30	30
k	15	6	4		2		1	28	28
j	3	1			2			6	6
ʎ	2	1	1		2			6	6
v	2	1						2	2
f	2	2	1		1			6	6
ʒ	1	2						1	1
ʃ	4	2						6	6
e	1							1	1
ə	1	3			1			6	6
z	2	1	1		7			10	10
s	6	1	4		7			20	20
m	5	3	2		7		1	9	9
n	11	3	11		1		1	25	25
ŋ	2	1	2					5	5
l	9	5	6					17	17
r	5	3	14					29	29
#	4	3						7	7

Table 7. Sentence List

1. The wagon moved on well oiled wheels.
2. The fleas hopped on both the cat and the chair.
3. Never buy a blind pig in a bag.
4. March the soldiers past the next hill.
5. A cup of sugar makes sweet fudge.
6. Place a rose bush near the porch steps.
7. George gave his sister a lot of coin.
8. Both lost their lives in the raging storm.
9. We talked of the side show in the circus.
10. Use a pencil to write the rough draft.
11. He ran half way to the hardware store.
12. Eightcops visit the new cook.
13. A cute baby is not shy or corss.
14. The clock struck to mark the third period.
15. College girls are full of zip and verve.
16. A small creek cut across the field.
17. Boys thrive on rough games and candy.
18. Cars and buses stalled in snow drifts.
19. The set of china hit the floor with a crash.
20. May is a grand season for hikes on the road.

Table 7. Sentence List (cont.)

21. He told the queen to mend her harsh manner.
22. The slush lay deep along the street.
23. Seldom have I seen such a dope.
24. A wisp of cloud hung in the blue air.
25. Shave the whiskers and show your own face.
26. Type one is right, the doctor said.
27. A pound of sugar costs more than eggs.
28. The fin was sharp and cut the clear water.
29. The play seems dull and quite stupid.
30. Sail the boat to stop it from sinking.
31. The term ended in late June that year.
32. The team fell into a mean humor then.
33. The hoary rock was huge and rose high.
34. A tusk is used to make costly gifts.
35. Ten pins were set in order.
36. The bill was paid every third week.
37. Oak is strong and also gives shade.
38. Cats and dogs each hate the other.
39. The park stretched from the pond to the ancient house.
40. Rooms to let go begging this spring.

Table 8. Revised 50 item word list.

blush	fused
champ	scrub
sledge	tongue
grove	earthquake
bind	charge
sleeps	more
barb	cute
showered	scarecrow
chant	dwarf
bounce	daybreak
train	inkwell
shank	shipwreck
sketch	buckwheat
joke	sheep
spice	woodwork
thread	starlight
bush	platform
duckpond	mushroom
with	schoolboy
crown	washboard
playground	eggplant
drawbridge	wildcat
twist	northwest
shrug	lifeboat
cookbook	man

both of the University of Michigan and the Ann Arbor Veteran's Administration Hospital, served as speakers. Each dysarthric was given a neurologic examination by staff members of the Department of Neurology. Clinical evaluation of each subject's speech based on a recording of conversation as well as the test materials was carried out by a member of the Speech Clinic staff. He provided a qualitative judgement of the severity of the dysarthric impairment. Recordings made by each of these speakers provided the material for acoustic-phonetic analysis and initial intelligibility studies. A second group of 20 dysarthric speakers recorded the revised 50 word list for the second intelligibility study. These speakers were recorded in several centers and hospitals around the country. The essential clinical and biographical data for all dysarthric speakers is given in Table 9. Data from both groups of dysarthrics were employed in the analysis of the revised word list.

Ten normal speakers were selected as a control group for the original sample of dysarthrics. An attempt was made to select normals that approximated the dysarthric group in age, education and occupational status. Table 10 presents the biographical data for these speakers.

In the first series of intelligibility studies, 30 different listeners responded to each talker. Ten different listeners responded to each talker's recording of the 40 sentences. A total of 600 listeners participated in the ex-

Table 9. Biographical and clinical data for dysarthric subjects.

Patient	Age	Sex	Place of Birth	Time between onset and recording	Clinician's judgment of degree of dysarthric impairment	Etiology	Related speech finding as judged by the clinician where recording made
(2) O.B.	57	M	Wilburton, Okla.	7 yrs.	Moderate	CVA	Paraphrasia, motor aphasia
(2) F.B.	65	M	San Francisco, Calif.	9 yrs.	Moderate	CVA	Residuals of motor aphasia
(2) R.B.	54	M	Morhall, Maryland	6 mos.	Mild	Thrombosis	None
(2) J.B.	43	M	McAllister, Okla.	1 yr.	Mild	Thrombosis	Amnesic aphasia, Formulation and spelling loss, acalculia
(1) F.B., Jr.	42	M	Michigan	4 yrs.	Moderate	Posttraumatic brain and cerebellar deficit	None
*(1) J.F. B.	65	M	Oklahoma-Michigan	2 yrs.	Very severe	Progressive bulbar palsy	Loss of labial and lingual function

*Used in spectrographic analysis only.

**These are findings in addition to dysarthria and when listened to by experimenter judged not to interfere with participation in experiment.

Table 9. (cont.) Biographical and clinical data for dysarthric subjects.

Patient	Age	Sex	Place of Birth	Time between onset and recording	Clinician's judgment of degree of dysarthric impairment	Etiology	Related speech finding as judged by the clinician where recording made
(2) F.C.	41	M	Mt. Harris, Colo.	6 mos.	Moderate	Cerebellar Atrophy	Ataxia
(1) O.D.	68	M	Michigan	3 yrs.	Severe	CVA embolism	None
(2) R.G.	29	M	Denver, Colorado	11 yrs.	Mild	Multiple Sclerosis	None known
(1) G.H.	35	M	Battle Creek, Michigan	2 yrs.	Severe	Post-Encephalitic	None
(2) O.H.	42	M	South Dakota	13 yrs.	Moderate	CVA	None
(1) D.H.	38	M	Yonkers, New York	3 yrs.	Moderately severe	Closed head injury	None known
(2) R.H.	24	M	Baker, Oregon	5 mos.	Very mild	Auto accident	Ataxia
(2) R.Hen.	64	M	Arkansas	4 yrs.	Severe	CVA	Motor aphasia

Table 9. (cont.) Biographical and clinical data for dysarthric subjects.

Patient	Age	Sex	Place of Birth	Time between onset and recording	Clinician's judgment of degree of dysarthric impairment	Etiology	Related speech finding as judged by the clinician where recording made
(1) L.K.	20	M	North Dakota	4 yrs.	Moderately severe	Posttraumatic encephalopathy	None known
(2) C.K.	21	M	Detroit, Michigan	16 yrs. (?)	Mild	Huntington's chorea	Mild choreatic speech
(2) E.La.	50	M	El Paso, Texas	4 yrs.	Mild	Trauma	Amnesic Aphasia
(2) E. Ly	27	M	Toledo, Ohio	4 yrs.	Mild	Trauma-frontal lesion	None
(2) H.M.	44	M	Denver, Colorado	4 yrs.	Mild	Encephalitis	Ataxia
(2) J.M.	25	M	Longbeach, Calif.	8 yrs.	Severe	Trauma	None
(2) D.O.	30	M	Mass.	9 yrs.	Severe	Trauma-Frontal	None
(2) F.P.	46	M	Montana	24 yrs.	Very mild	MS	None known
(2) J.P.	56	M	Los Angeles, Calif.	3 yrs.	Mild	CVA	Amnesic aphasia Oral formulation loss

Table 9. (cont.) Biographical and clinical data for dysarthric subjects.

Patient	Age	Sex	Place of Birth	Time between onset and recording	Clinician's judgment of degree of dysarthric impairment	Etiology	Related speech finding as judged by the clinician where recording made
(1) B.S.	38	M	Michigan	33 yrs.	Moderate	Frederick's ataxia	None known
(1) C.S.	25	M	Michigan	5 yrs.	Moderate	Posttraumatic upper brain stem damage	Moderate dysphonia
(2) D.S.	40	M	Arkansas	5 yrs.	Moderate	M.S. Mid-brain	None known
(1) F.S.	47	M	Wyandotte, Michigan	26 yrs.	Moderately severe	Unilateral Parkinson's disease	None known
(2) H.T.	53	M	Missouri	3 yrs.	Severe	Embolus to basilar artery system	None
(2) G.W.	16	F	Michigan	1 yr.	Moderate-Mild	Cerebellar lesion	Ataxia
(1) A.Z.	52	M	Indiana	4 yrs.	Severe	CVA	None known

(1) Used in Intelligibility Study I.

(2) Used in Intelligibility Study II.

Table 10.. Biographical data for the normal subjects.

Subject Number	Age	Education	Occupation
1N	28	B.A.	Teacher-coach
2N	20	College: 2 yrs.	College Student
3N	48	Ph.D.	College Teacher
4N	36	High School	Mail Carrier
5N	51	High School	Barber
6N	26	M.A.	Graduate Student
7N	59	High School	Group Leader
8N	50	Ph.D.	College Teacher
9N	36	9th Grade	Farmer
10N	63	High School	Farmer

periments. The listeners were students in speech courses at The University of Michigan. Three hundred additional listeners served in the second intelligibility study.

Analyses of the reliability of response on a word by word basis suggested that 15 listeners per talker be used in the study of intelligibility based on the revised word list.

Recording Procedures. For the first series of experiments, (i.e. acoustic-phonetic analyses and initial intelligibility studies) all recordings were made with an Ampex Tape Recorder, Model 350, and Altec Microphone, Model 660. Whenever possible, the recordings were made in the soundproof recording room of the Communication Sciences Laboratory. In two instances the recordings were made in a sound treated room provided by the Department of Neurology at the University of Michigan Medical Center.

Speakers repeated the test words after the experimenter, and read the sentences from a typewritten sheet.

The recordings of the second group of dysarthrics were not made under similar conditions. The recording equipment employed was that available at the various centers from which speakers were recruited. In addition, there was some variation in the amount of background noise present in the recordings. Some potential speakers were not used because of background noise or poor recording quality. Tape speed in all cases was 7 1/2 ips.

Acoustic-Phonetic Analysis. Recordings made by all speakers were subjected to spectrographic analysis. The Bell Telephone Laboratories' Model D Sound Spectrograph at the Communication Sciences Laboratory of the University of Michigan was employed for the analysis. In addition to the broad-band spectrograms made of all the words recorded, narrow-band spectrograms and continuous amplitude displays were made of a selected set of utterances. Approximately 3000 spectrograms were examined for this aspect of the research program.

Two analyses of the spectrographic data were carried out. The first, executed by Dr. Ilse Lehiste,³ was concerned with providing a detailed acoustic-phonetic analysis of dysarthric speech. To achieve this end the following measures were made on each spectrogram:

1. The center frequency of the first three formants at the target or steady state of the syllable nucleus.
2. The duration of the syllable nucleus.
3. Formant positions at the point of transition from the initial consonant to the syllable nucleus and at the point of transition from the syllable nucleus to the final consonant.
4. The duration of the initial and final consonants.
5. The formant positions within the resonant consonants.
6. The frequency of energy concentrations in fricative consonants and in the releases of plosives.

³ Co-investigator while at The University of Michigan. Now at Ohio State University.

Complete details of the procedures and standards for measurement and interpretation are given in the monograph entitled, "Some Acoustic Characteristics of Dysarthric Speech,"⁴ by Dr. Lehiste.

The second analysis was concerned only with comparing and studying the vowel production of the dysarthrics and their controls. Many of the measures on the vowels for the analysis carried out by Lehiste were used for this study. However, the spectrograms for vowel production of all the normal controls were examined. This analysis did not require all of the measures described above. Only the center frequency of the first two formants at the target or steady state of the syllable nucleus were employed. A gross statistical analysis of the formant frequencies was carried out. The results of this analysis are given in the results section of this report. Most of the work for the vowel study was carried out by Rita Tikofsky, who also assisted Dr. Lehiste in her spectrographic analyses.

⁴ The monograph was completed as part of the research carried out for this project and is submitted along with the final progress report. The complete reference is: Lehiste, Ilse, Some Acoustic Characteristics of Dysarthric Speech, Bibliotheca Phonetica, Fasc.2, (1965).

Intelligibility analysis. Four studies of dysarthric intelligibility were carried out in the course of the research program. While the information varied in each study, the approach to data collection and analysis did not vary markedly from experiment to experiment.

For the first intelligibility experiment sets of listening tapes containing each of the three word lists was prepared from the original tapes recorded by each speaker. Three listening tapes were prepared for each listener. Instructions to the listeners were recorded on these tapes. Each tape had one of three word list orders: CNC-Clusters-Spondees; Clusters-Spondees-CNC; and Spondees-CNC-Clusters. Using this pattern no list appeared in the same position on any two tapes for a given speaker. The listening tapes were played to listeners through a single TDH39 earphone at a comfortable intensity level. The opposite ear was covered with a dummy earphone. Generally, five listeners were present at each group listening session. Ten different listeners responded to each listening tape for each speaker. Listeners were instructed to write the word they thought they heard through the earphone on a record sheet. If they did not understand the utterance, they were asked to draw a line alongside the appropriate

number on the answer sheet. The instructions given to the listeners on the tape recording are given in Appendix I. All listening sessions were held in quiet rooms with minimal amounts of outside or ambient noise.

Data obtained from the experiment described above was used for two of the four intelligibility studies. For the first evaluation of intelligibility only gross measures were made. A speaker's intelligibility was defined as the number of words correctly identified by the listeners. Four separate intelligibility scores were derived: (a) total intelligibility, the total number of correct responses made by all listeners for a given speaker for the three word lists; (b) total order intelligibility, the total number of correct responses made by all the listeners for a given speaker for each order of word list presentation; (c) list intelligibility, the total number of correct responses made by all listeners for a given speaker for each word list, without regard to the position of the list on the listening tapes; and (d) list-by-order intelligibility, the total number of correct responses made by all of the listeners for a given speaker on a word list occurring in a particular order on the listening tape.

These scores were subjected to statistical analyses. Results of the analyses are described in the next section

of this report and in the papers presented at professional meetings. These papers are found in the appendices of this report.

A computer program was developed for the second part of the first intelligibility program. This aspect of the research on intelligibility was concerned with the errors made by listeners in response to the CNC words. The number as well as type of consonantal errors made for initial and final consonants for each speaker was tabulated. In addition, these counts were summed across all speakers. A copy of the final confusion matrices for dysarthric and normal speakers along with the flow diagram and key punch code appear as Appendix II. Results of this analysis will be described later.

An analysis of listener responses to sentences read by dysarthrics and normals was carried out. Speakers in this experiment were the same as those used to obtain the single word intelligibility data described above. Ten different listeners responded to each tape under the same conditions described for the initial single word intelligibility study. Listeners were told to listen to the complete sentence (each sentence was presented twice in rapid succession) and then to write what they thought they heard. Instructions indicated that the stimuli

would be complete sentences, not just word-phrases.

A computer program to score and tabulate the errors for each speaker and all speakers in the two groups, dysarthrics and normals, was written. The computer output included the word substitutions, total word errors and the rank order of the errors.

A sentence intelligibility score for each speaker was computed. This score represented the percent correct responses and was obtained by dividing the number of errors made by the total number of possible errors. The total number of possible errors equaled the number of words contained in all sentences (312) multiplied by the number of listeners per speaker. (10). Thus, there were a possible 3120 responses/ speaker. Intelligibility curves for each speaker as well as the relative intelligibility of the stimulus words for the two groups of speakers were studied. These scoring and analytic procedures served as the source for interpreting the intelligibility of dysarthrics using short sequences of connected speech.

The first three investigations of measures of dysarthric intelligibility used the same population of normal and dysarthric speakers. In part, they were concerned with comparing the dysarthric and normal. It was evident, as will be seen in more detail in the Results section, that the two groups in no way overlapped on the measures obtained.

However, the results of the first word intelligibility study suggested that further work in this area on the dysarthric was warranted.

As a first step in the preparation of a follow-up study of dysarthric intelligibility, an item analysis was carried on the 160 words which made up the stimulus material used in the initial studies. Our goal was to reduce the 160 word list to the 50 words which might best be used in the follow-up experiments. A standard and available computer program was used on the IBM 7090 computer to carry out the analysis. The resultant 50 word list contained the most reliable items (minimum reliability of .550 with a range of .550 to .805); the highest variance items (yielding maximum spread); and the items nearest the mean difficulty range of the item sample. Difficulty level ranged from .407 to .841 over nine levels of difficulty in increments of .050 steps. This new list contained 6 CNC, 20 spondee and 24 cluster words.

The revised list was recorded by a new sample of dysarthric speakers described in the section on subjects above. Listening tapes of these dysarthrics were presented to listeners in the same manner as in the first word intelligibility study. Fifteen different listeners for each talker served as respondents in this experiment.

Listener responses were examined to determine the range of agreement among listeners as well as the range of difference between dysarthrics. The number of words correctly identified was also used as the measure of intelligibility for this study.

Results

Acoustic-Phonetic Studies: The first results of the spectrographic analysis of dysarthric speech were based on a study of two dysarthric speakers. A preliminary report of the findings was made by Dr. Lehisté, then co-principal investigator. The report appears as Appendix III.

Her analysis of the spectrograms suggested that dysarthrics show at least one, but more often several, of the difficulties noted below:

1. Lack of coordination between phonation and articulation.
2. Difficulty in performing controlled movements.
3. Difficulty in kinesthetic monitoring of point and manner of articulation.

This preliminary analysis was extended to a description of all of the dysarthrics and a comparison with a normal speaker. Results of the extended analysis were presented at the meetings of the Acoustical Society of America and the American Speech and Hearing Association in 1961. (Appendices IV and V.) An attempt was made to relate

the spectrographic findings to intelligibility as determined by listener responses. It was found that in some instances it was possible to predict listener errors from the spectrographic data. While this was not universally true for all speakers, it occurred quite frequently for several speakers. There was on the other hand no clear-cut relation between etiology, time since onset and the nature of the type of difficulty in speech production as deduced from the spectrograms. This in part may be accounted for by the small sample of speakers as well as the lack of precision in determining the locus of the lesion producing the dysarthric symptoms.

The major area of difference in the spectrograms of dysarthrics and normals appeared in production of consonants. Some differences were also noted in the analysis of the vowels. Initial comparison of the vowel diagrams of a dysarthric and a normal suggested some compression of the diagram and shift in average formant frequencies. A separate analysis of the vowels was undertaken and includes all normal speakers as well as dysarthrics. The results of this analysis will be discussed later.

A detailed description of the speech of the ten dysarthric speakers who participated in the first segment of the research program was carried out by Dr. Lehiste. In addition to the individual descriptions, Dr. Lehiste summarized the dysarthric features observed in the ten

speakers. Her findings have been published as an entire issue of *Bibliotheca Phonetica*.⁵

A comparison of vowel production between dysarthrics and normals was carried out. It appeared that, despite marked differences in consonant production and intelligibility between the two groups of speakers, accuracy of vowel production by dysarthrics as determined by spectrographic analysis was very much the same as for normals. To assess this apparent similarity, a detailed study of the F_1 and F_2 characteristics of the 11 vowels employed in the test lists was carried out.

For this study, only nine of the ten dysarthrics was analyzed. One speaker was considered as anarthric and was almost completely unintelligible. Thus, he and his control were not included in this or the intelligibility studies.

F_1 and F_2 measurements were made for all of the vowels produced at the steady state segment of the utterance. Measurements were within an accuracy range of #25 cps.

Means and standard deviations for F_1 and F_2 were computed for each vowel for each of the two groups of talkers and

⁵Ibid.

for each speaker. Table 11 presents the mean F_1 and F_2 frequencies for each of the 11 vowels across all speakers in the two groups. It also shows the standard deviations and range of means and standard deviations for the vowels

For the most part, the mean F_1 values for dysarthrics and normals are quite similar. However, the range of mean values for a given vowel show greater variability for the two groups of speakers. Normal speakers tend to show a greater dispersion than do dysarthrics. This is also reflected in the size of the standard deviations and range of standard deviations within vowels.

There is a tendency for the mean F_2 values for the two populations to be further apart than there is for the F_1 values. However, there seems to be no particular pattern to the observed differences.

The means and standard deviations reported in Table 11 were used to illustrate graphically the general configuration of the vowel diagrams for the two populations of speakers. Figure 1 is the vowel diagram based on the mean F_1 and F_2 measurements for each vowel for all speakers. Figures 2 and 3 permit a graphic comparison to be made between groups for each of the formants. These diagrams illustrate a remarkable degree of agreement in terms of their general shape and positioning. Such a

Table 11. Range of Means and Standard Deviations for F_1 and F_2 frequencies for 11 vowels for normal and dysarthric speakers.

Range of Means F ₁		Means F ₁		Range S.D. Units F ₁		S.D. Units		Range of Means F ₂		Means F ₂		Range S.D. Units F ₂		S.D. Units		Number occurrences vowel in sample
		D	N	D	N	D	N	D	N	D	N	D	N	D	N	
**																
Vowels																
i	47	30	366		142		16.7		264		2133		277		74.4	10
			343		44		9.6		200		1908		121		71.2	
I	89		403		140		33.5		325		1736		275		95.3	18
	123		434		100		29.5		350		1635		191		97.4	
I ^e	167		409		168		42.0		361		1982		315		88.4	15
	100		413		117		33.9		308		1800		155		44.5	
æ	106		628		73		96.4		503		1691		197		124.0	20
	84		603		96		10.2		336		1525		200		82.5	
ɛ	178		148		65		52.7		522		1623		273		117.0	23
	148		528		105		35.4		533		1511		193		130.0	
ə	92		619		105		44.2		233		1183		104		65.0	18
	86		596		103		21.7		289		1175		160		85.8	
a	156		665		169		40.5		170		1200		96		36.9	22
	94		633		100		69.9		150		1163		176		40.8	
ɔ	226		517		64		75.0		353		953		109		94.4	20
	136		537		125		44.8		228		968		113		71.8	
o	127		426		108		35.2		100		832		96		37.6	10
	78		465		95		26.0		133		891		169		41.7	
u	59		427		66		21.2		245		1063		147		78.7	6
	50		438		22		17.1		184		975		66		65.1	
u	92		397		108		26.9		431		996		198		178.3	11
	90		388		91		15.9		242		925		214		90.4	

**The means represent the mean value based on mean for all speakers in each group.
 **Upper figure represent N, lower D.

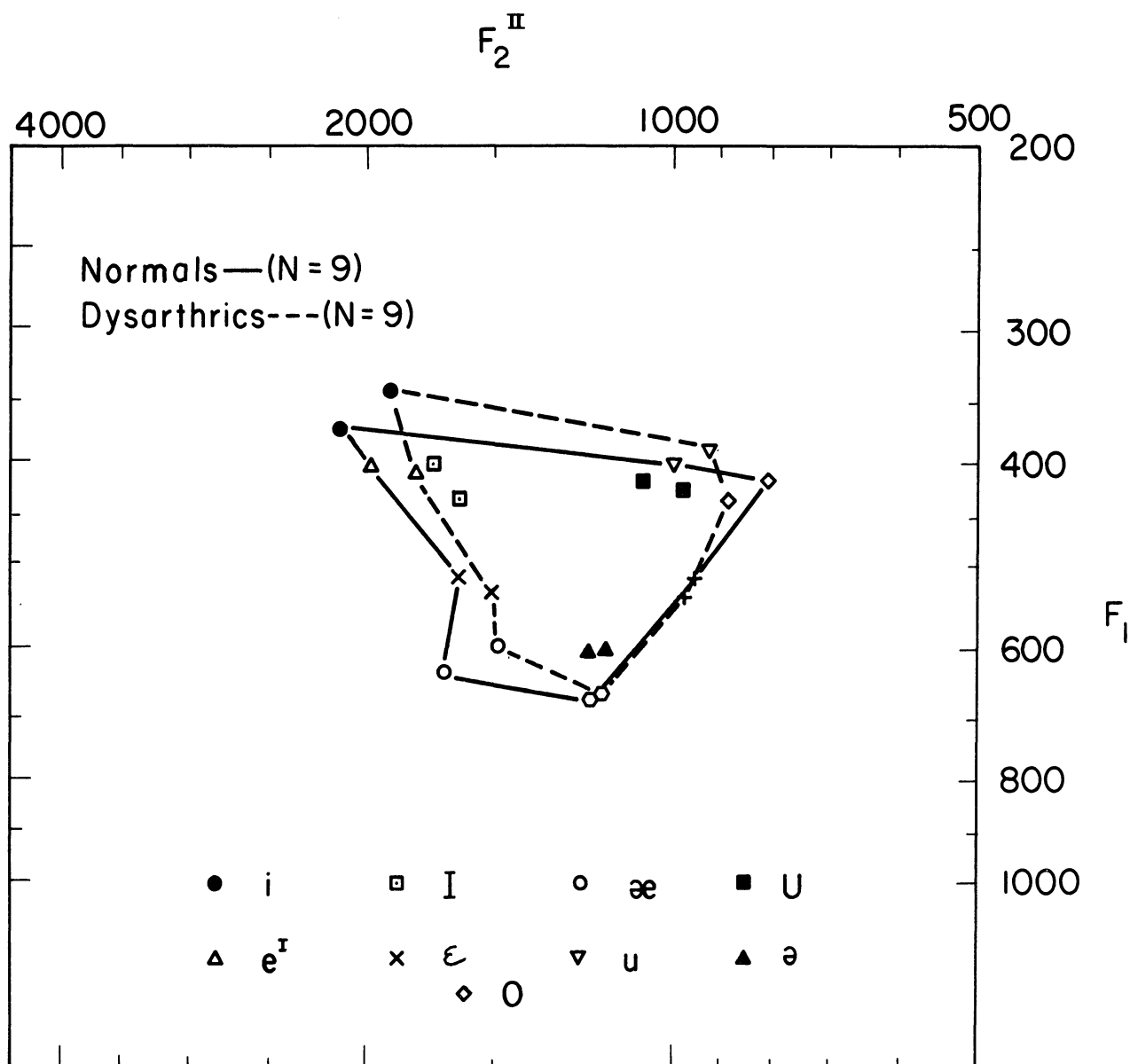


Figure 1. Mean frequency of vowels for all speakers for 11 vowels for F_1 versus F_2 .

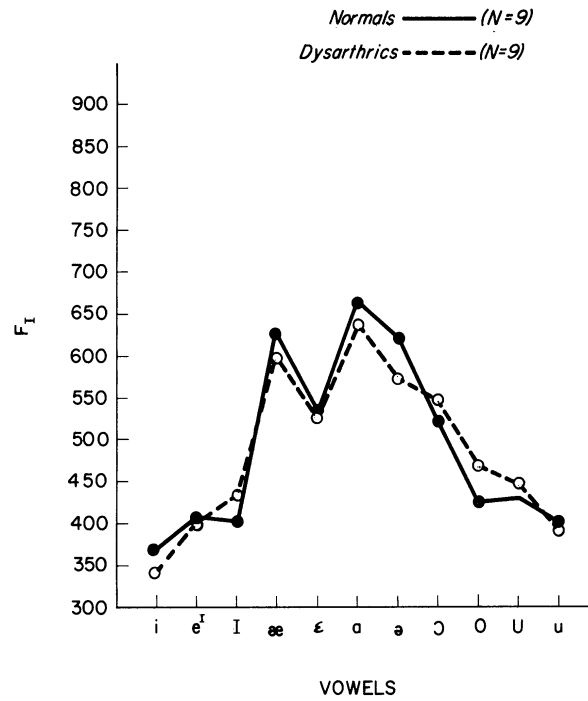


Figure 2. Mean frequency of vowels for all speakers on 11 vowels for F_1 .

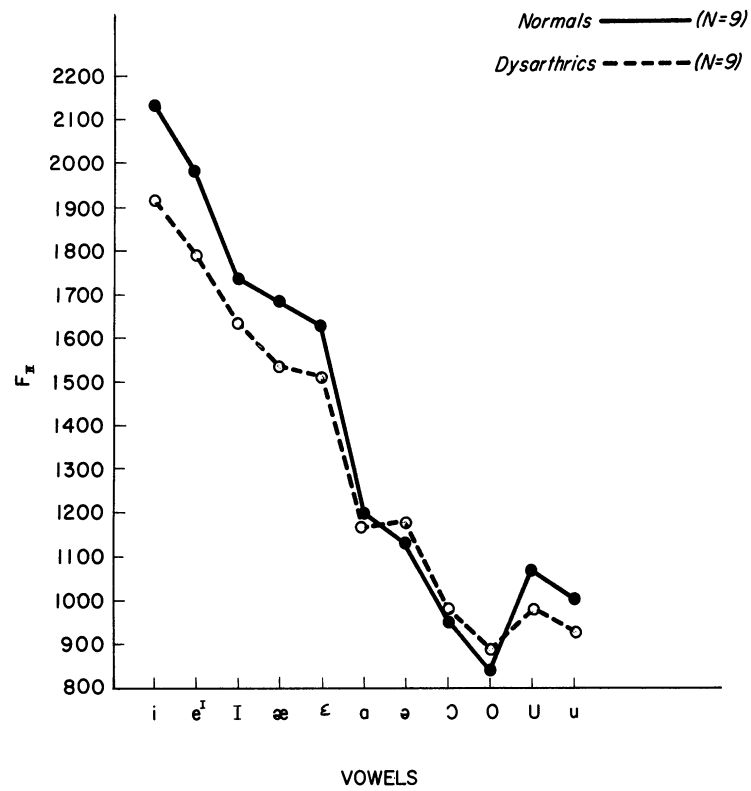


Figure 3. Mean frequency of vowels for all speakers on 11 vowels for F_2 .

finding was not expected in view of the marked difference in intelligibility and other features of speech production between dysarthrics and normals. This apparent absence of difference may be accounted for by the fact that the formants were measured during the steady state of vowel production, and the dysarthric impairment shows up most often in the transitions. Secondly, use of the mean values mask differences in the variability present in the two populations. The differences and similarities in means and standard deviations are illustrated in figures 4 and 5. These figures show, not only the mean formant frequencies for the vowels, but also the range of variability around the mean for F_1 and F_2 for each vowel. The vertical lines originating at the mean values are values for one standard deviation above and below the mean. The range of difference within and between the groups for each of the formants now stand out. There is obviously considerable overlap, but on the whole the standard deviations for dysarthrics are somewhat smaller than those observed for normals.

Figures 6 and 7 are plots of the individual mean F_1 and F_2 values for normals and dysarthrics, respectively. While the general configuration for the two groups was generally the same and for the most part is in agreement

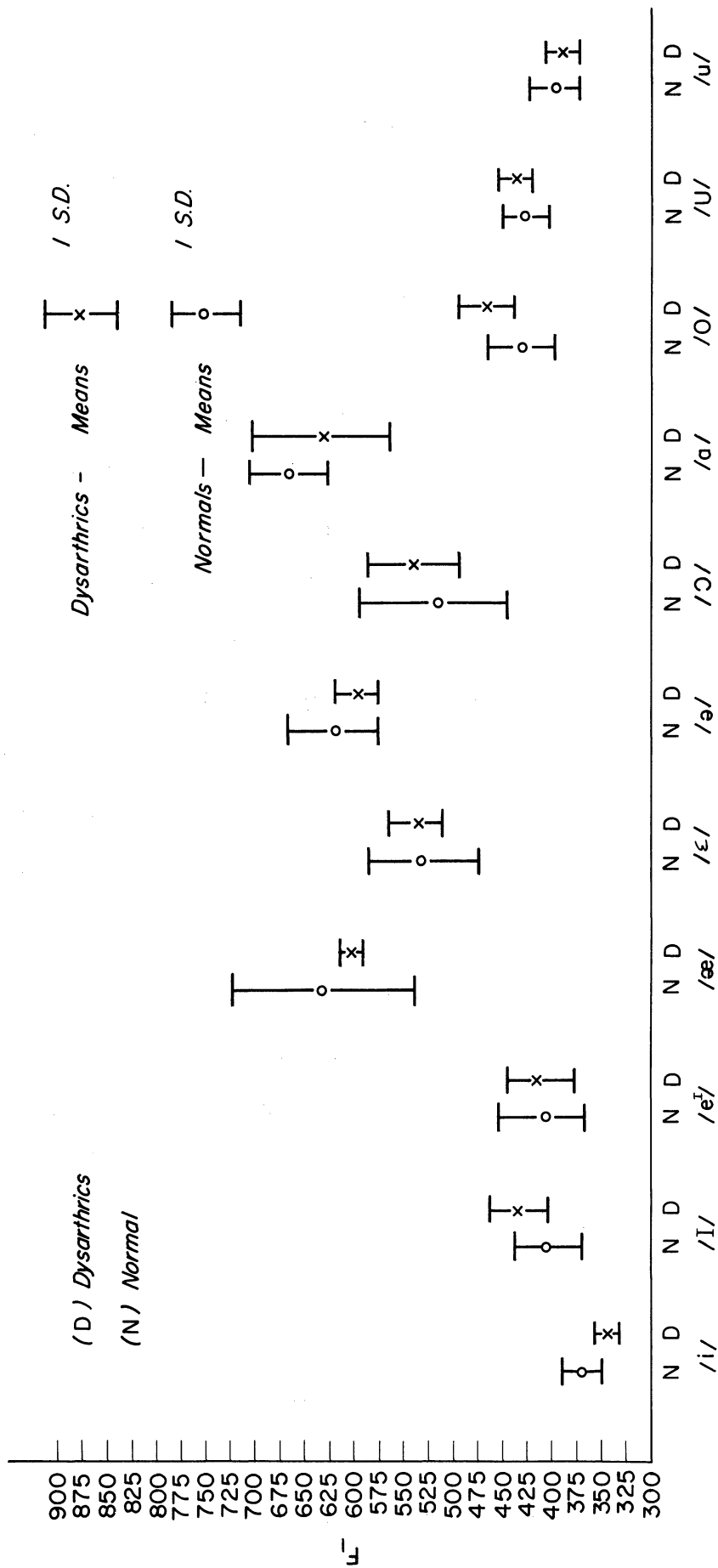


Figure 4. Means and standard deviations of vowels for all speakers on 11 vowels for F₁.

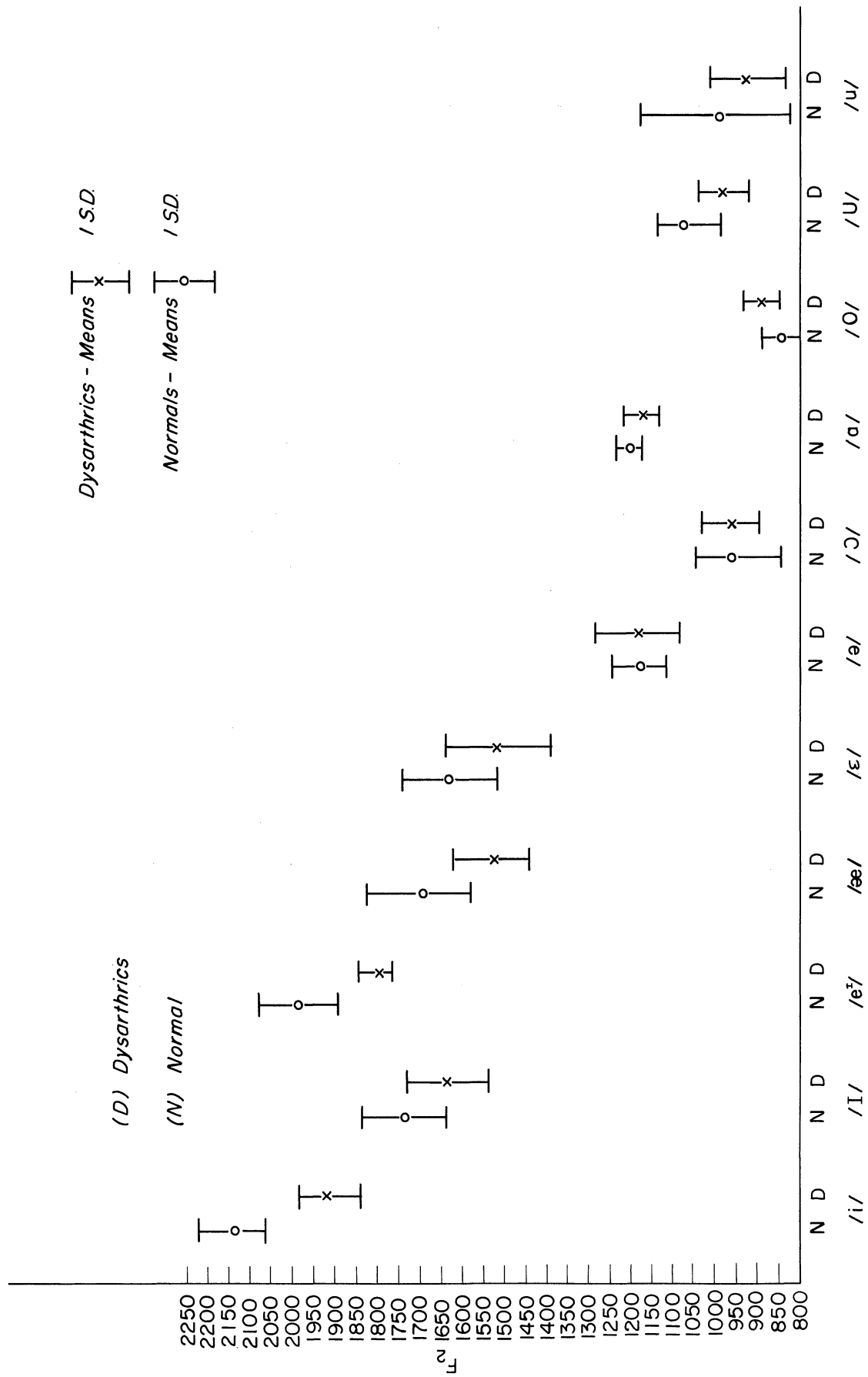


Figure 5. Means and standard deviations of vowels for all speakers on F₂.

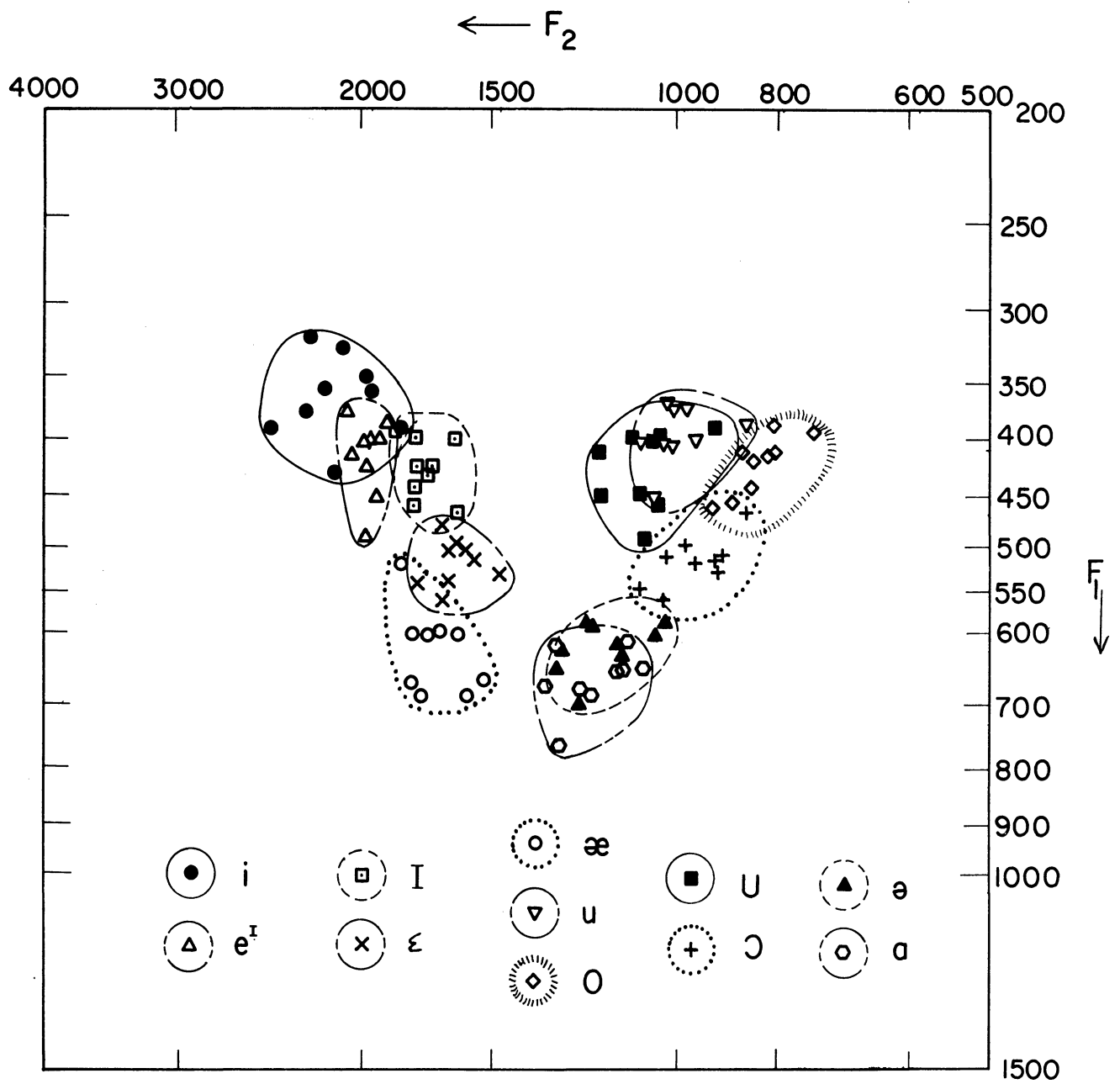


Figure 6. Frequency of F_2 versus F_1 for vowels spoken by 9 normal speakers.

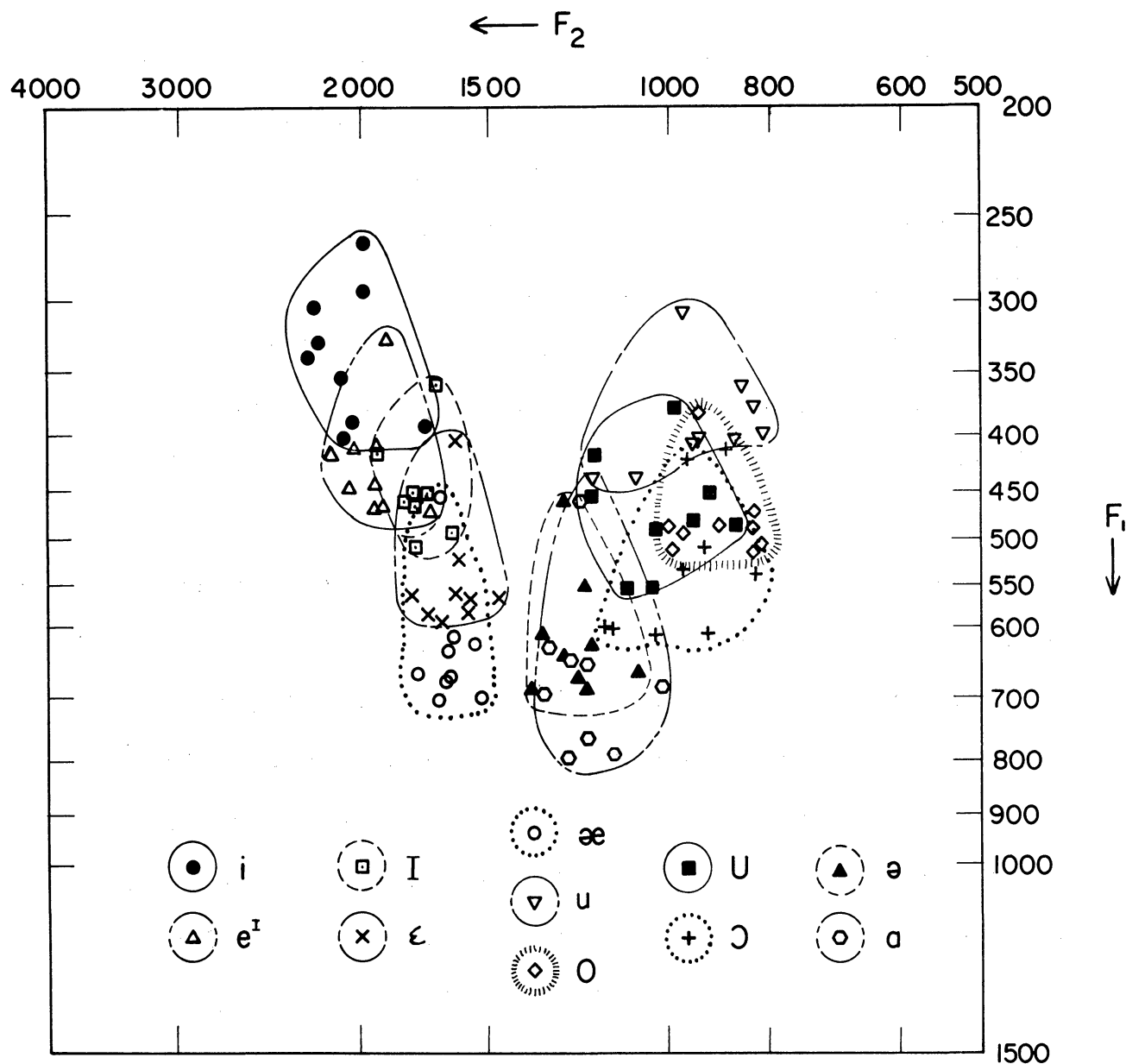


Figure 7. Frequency of F_2 versus F_1 for vowels spoken by 9 dysarthric speakers..

with similar data reported by Peterson and Barney.⁶ Our data show greater overlap between /u/ and /ʊ/ as well as /ɔ/ and /a/ than Peterson and Barney report.

The degree of dispersion of mean formant frequencies when individual speakers are considered is greater for dysarthrics than for normals. Much of this difference is accounted for by values produced by one dysarthric subject.

In summary, the acoustic-phonetic analysis of dysarthric speech reveals important clues relating to the articulatory and phonatory difficulties experienced by these speakers. It is our feeling that knowledge gained from spectrographic analysis can be profitably employed in developing techniques for speech therapy with these patients. Further changes in speech production following therapy could be expected to be reflected in changes in the spectrographic patterns. However, it does not seem likely that spectrographic analysis is a good predictor of listener errors of intelligibility.

⁶Peterson, G.E., H.L. Barney. Control methods used in a study of vowels. J. Acoust.Soc. Amer. 24, 175-184 (1952).

Intelligibility studies. Intelligibility Study I was confined to a comparison of the scores made by listeners to normal and dysarthric speakers. In addition, an attempt was made to determine if intelligibility varied with list (CNC, Cluster words or Spondees) or was influenced by the order in which the lists were presented to the listeners. Results of this initial analysis were presented at the Acoustical Society of America in 1961 (Appendix VI.) A second paper on intelligibility was presented to the American Speech and Hearing Association in 1963 (Appendix VII) and was published in the Journal of Speech and Hearing Research.⁷

In summary, the initial word intelligibility analyses showed that dysarthrics differ from normal speakers on the intelligibility measures used in this study. The ranking of the dysarthric subjects was stable across lists and orders of presentation. These findings indicate that a speaker's rank on one list can be predicted from his rank on any of the other lists.

Statistically significant differences were obtained among dysarthrics. There does not appear to be a significant list or order of presentation effect. However, some dysarthrics have more difficulty in producing intelligible speech on one list than on another. This does not seem

⁷Tikofsky, R.S. and R.P. Tikofsky. Intelligibility measures of dysarthric speech. J. Speech Hearing Res. 4, 325-333 (1964.) Copies of this paper are submitted along with this report.

to be directly related to degree of impairment or etiology. In some cases there appears to be a slight practice effect.

An analysis of the type and frequency of consonantal confusions made by listeners to the 50 CNC words recorded by the dysarthric and normal speakers was carried out. Results indicate that there is essentially no difference in the proportion of confusions for initial and final consonants. The least intelligible consonants for dysarthrics were those involving rapid shifts of articulatory position such as /dʒ/. The consonant least confused by listeners was /s/ in the initial position and /r/; /l/ and /m/ in the final position. No clearly distinctive patterns of consonantal confusions appeared which could be said to characterize the population of dysarthrics as a whole. Rank order of difficulty for each consonant based on proportion of listener confusions varied greatly from dysarthric to dysarthric. Significantly fewer confusions are made for normal speakers than for dysarthrics. A paper reporting this study was read at the American Speech and Hearing Association in 1964 and a revision has been submitted to *Folia Phoniatrica* for publication. (Appendix VIII.)

In re-examining listener responses to the dysarthric speakers it became evident that many of the words which made up the three lists contributed little to the estimate of the estimate of the speaker's intelligibility. It appeared that a more efficient, or at least as efficient, estimate of dysarthric intelligibility could be obtained from a subset of the words used in Intelligibility Study I. We felt that, if possible, a new list should contain the 50 "best" words of the total available sample of 160 words.

An item analysis was carried out on each of the 160 words. The analysis was carried out on the IBM 7090 Computer at The University of Michigan Computing Center. The results of the analysis for all the words in each list, lists combined and the 50 item list, are given in Table 12. The higher the difficulty level (Mean Difficulty in the table) the easier the item was to identify. The set of 50 words finally selected for the new list had the following characteristics:

1. Nine difficulty levels from .400 to .800 (.050 interval width)
2. Average difficulty of .619
3. Average variance of .222
4. Average standard deviation of .472
5. Average reliability of .676

Table 12. Summary Table for Item Analysis on Word Data for Intelligibility Study I.

	CNC List	Clusters List	Spondee List	All lists combined	50 item list
Mean Difficulty	.578	.510	.752	.607	.619
Difficulty Range	.096 to .944	.230 to .815	.567 to .978	.096 to .978	.407 to .852
Mean Variance	.212	.231	.178	.208	.222
Variance Range	.053 to .250	.151 to .250	.022 to .246	.022 to .250	.134 to .250
Mean Standard D.	.458	.480	.415	.453	.472
Standard D. Range	.230 to .500	.389 to .500	.148 to .496	.148 to .500	.366 to .500
Mean Reliability	.427	.527	.445	.458	.676
Reliability Range	-.362 to .748	.037 to .821	.010 to .737	-.302 to .805	.550 to .805

6. Difficulty range of .407 to .852
7. Variance range of .134 to .250
8. Reliability range of .550 to .805
9. Minimum reliability cut-off of .550

Table 13 presents the revised 50 word list, the difficulty levels, difficulty variance, reliability for each word. Also included in the table is the list from which the words were taken. Figure 8 is a plot of the mean number correct scores for listeners to the nine dysarthrics used in Intelligibility Study I. Subjects are numbered according to rank. Figure 9 shows the distribution of Standard Deviation units for the same speakers. The S.D. for the sample (i.e. across all speakers) was 11.76. These figures indicate that it was possible to distinguish between dysarthrics on the basis of the mean number of correct responses made by the listeners. It appeared from these preliminary results that the revised list might yield a clinically useful tool for quantitatively determining some aspects of the degree of dysarthric impairment.

Since 30 listeners responded to each speaker, we decided to test the degree of agreement among the listeners for the revised list. Each group of 30 listeners was random-

Table 13. Results of the item analysis for the revised 50 item word list.

	<u>Item</u>	<u>Difficulty</u>	<u>Variance</u>	<u>Reliability</u>	<u>List</u>
Difficulty level .400 [Interval .375-.425] Mean - .411	blush	.407	.241	.642	Cl
	champ	.415	.243	.606	Cl
Difficulty level .450 [Interval .425-.475] Mean - .461	sledge	.448	.247	.630	Cl
	grove	.467	.249	.607	Cl
	bind	.467	.249	.581	Cl
	sleeps	.496	.250	.732	Cl
	barb	.522	.250	.676	Cl
	showered	.496	.250	.640	Cl
	chant	.496	.250	.640	Cl
	bounce	.500	.250	.610	Cl
	train	.504	.250	.606	Cl
	shank	.519	.250	.558	Cl
Difficulty level .550 [Interval .525 -.575] Mean - .555	sketch	.563	.246	.756	Cl
	joke	.544	.248	.743	CNC
	spice	.563	.246	.725	Cl
	thread	.541	.248	.689	Cl
	bush	.533	.249	.647	CNC
	duckpond	.567	.246	.587	Sp
	with	.563	.246	.579	CNC
	crown	.567	.246	.550	Cl
Difficulty level .600 [Interval .575-.625] Mean -.640	playground	.619	.236	.805	Sp
	drawbridge	.611	.238	.757	Sp
	twist	.578	.244	.751	Cl
	shrug	.604	.239	.701	Cl
	fused	.607	.239	.725	Cl

Table 13. (Cont.) Results of the item analysis for the revised 50 word list.

Item	Difficulty	Variance	Reliability	List
Difficulty level .650 [Interval .625-.675] Mean - .657				
scrub	.663	.223	.778	Cl
tongue	.670	.221	.738	Cl
earthquake	.667	.222	.720	Sp
charge	.633	.232	.695	Cl
more	.659	.225	.694	CNC
cute	.652	.227	.693	Cl
scarecrow	.666	.222	.669	Sp
dwarf	.644	.229	.624	Cl
Difficulty level .700 [Interval .675-.725] Mean - .703				
daybreak	.711	.205	.759	Sp
inkwell	.700	.210	.710	Sp
shipwreck	.719	.202	.706	Sp
buckwheat	.693	.213	.697	Sp
sheep	.704	.208	.691	CNC
woodwork	.719	.202	.679	Sp
starlight	.704	.208	.675	Sp
platform	.678	.218	.675	Sp
mushroom	.685	.216	.660	Sp
schoolboy	.715	.204	.622	Sp
Difficulty level .750 [Interval .725-.775] Mean - .768				
washboard	.770	.177	.760	Sp
eggplant	.767	.179	.730	Sp
wildcat	.767	.179	.655	Sp
Difficulty level .800 [Interval .775-.825] Mean - .813				
northwest	.800	.160	.720	Sp
lifeboat	.811	.153	.680	Sp
man	.800	.160	.558	CNC
cookbook	.841	.134	.675	Sp

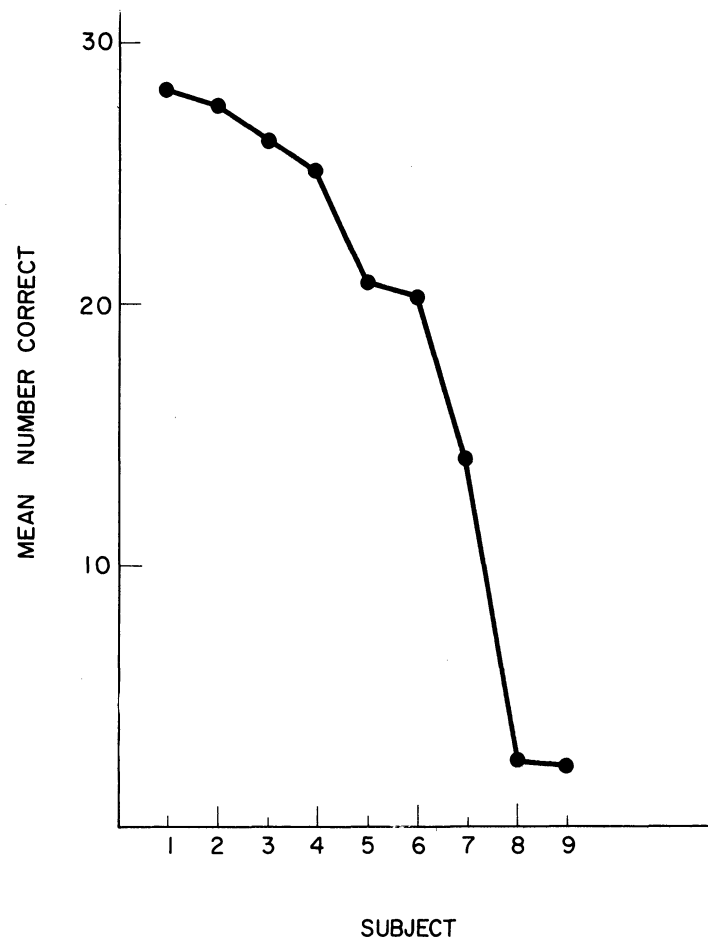


Figure 8. Distribution of mean number correct listener responses to each of 9 dysarthric speakers.

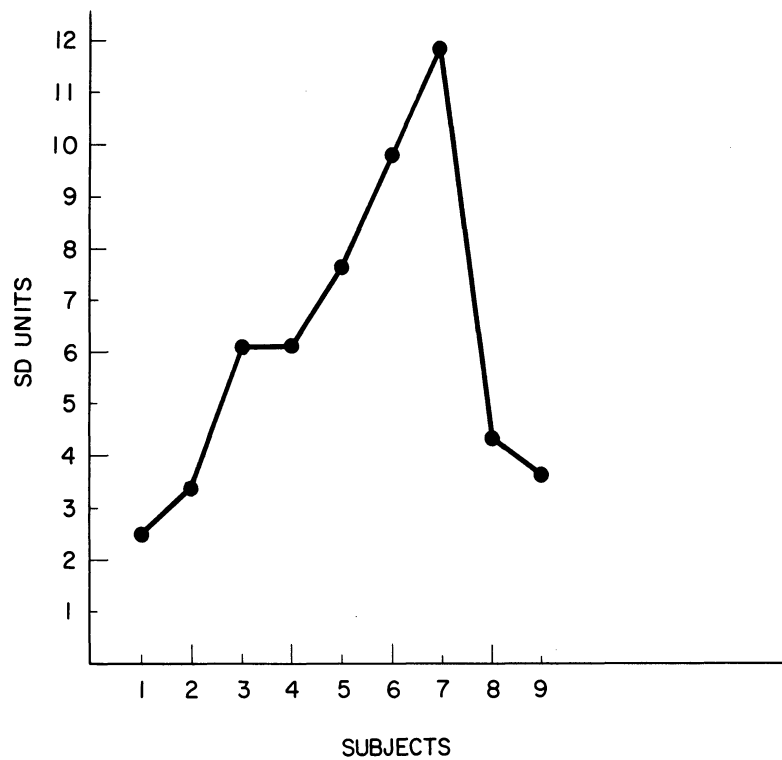


Figure 9. Distribution of Standard Deviation units for 9 dysarthric speakers.

ly assigned to one of two groups. A mean number correct score based on the responses to the 50 words were obtained for each group of 15 listeners for each speaker. Speakers ranked on the basis of mean number of correct responses. Thus, two sets of ranks were obtained, one set for each grouping of 15 listeners. A Spearman Rank Correlation was computed to determine the degree of agreement between the two sets of ranks. The obtained r_s was .99, which for an $N=9$ is significant beyond the .01 level. This indicates the intelligibility scores obtained for the 9 speakers was quite reliable.

Before beginning the Intelligibility Study II, which used the revised word list, we determined the minimum number of listeners necessary to obtain the most reliable estimates of intelligibility. We found that 15 listeners per speaker would yield the best estimates of reliability.

A new sample of dysarthrics was obtained and recorded as described in the Methods of Procedure Section. This study set out to achieve two goals. One was to determine whether the new list would produce a range of intelligibility scores which could ultimately be developed into a scale for estimating the degree of reduction of intelligibility of dysarthric speakers. The second goal was to see if the rank order of difficulty of the words

determined by listener responses would agree with the ranking of difficulty derived from the item analysis.

Table 14 gives the total number of correct responses, mean number of correct responses and the standard deviations obtained for the 20 dysarthrics who served as speakers in Intelligibility Study II. With 15 listeners per speaker, a total 750 responses for each speaker was obtained. It is clear from this table that, although there is a wide range of scores in terms of mean numbers of correct responses across speakers, the variability among listeners to a given speaker is quite low. Thus, it appears that this revised list can be employed to discriminate or estimate degree of dysarthric impairment based on listener responses.

The distribution of mean number of correct responses for the total population of dysarthric speakers (i.e. including the first 10 dysarthrics) according to rank is plotted in figure 10. Examination of this figure suggests that it should be possible to develop a scaling procedure based on these scores for the quantitative assessment of the reduction of intelligibility in dysarthric speakers.

As a preliminary to the development of such a scale, the range of correct responses for each speaker was tabulated. Table 15 presents the results of this tabulation.

Table 14. Raw scores, means and standard deviations for dysarthrics in Intelligibility Study II. (15 listeners per speaker.)

	Number of Correct Response Scores	Mean Number Correct	S.D.
S1	409	27.2	2.7
2	647	43.1	2.1
3	628	41.8	2.8
4	242	16.1	3.2
6	32	2.1	1.1
8	676	45.0	2.5
9	575	38.3	3.8
12	136	9.0	2.1
13	704	46.9	1.7
15	534	35.6	2.9
16	592	39.4	1.9
17	634	42.2	2.7
18	532	35.4	3.9
20	319	21.2	3.6
21	396	26.4	3.0
22	404	26.9	3.6
23	703	46.8	1.3
27	430	28.6	3.5
28	13	.87	.72
29	528	35.2	2.1

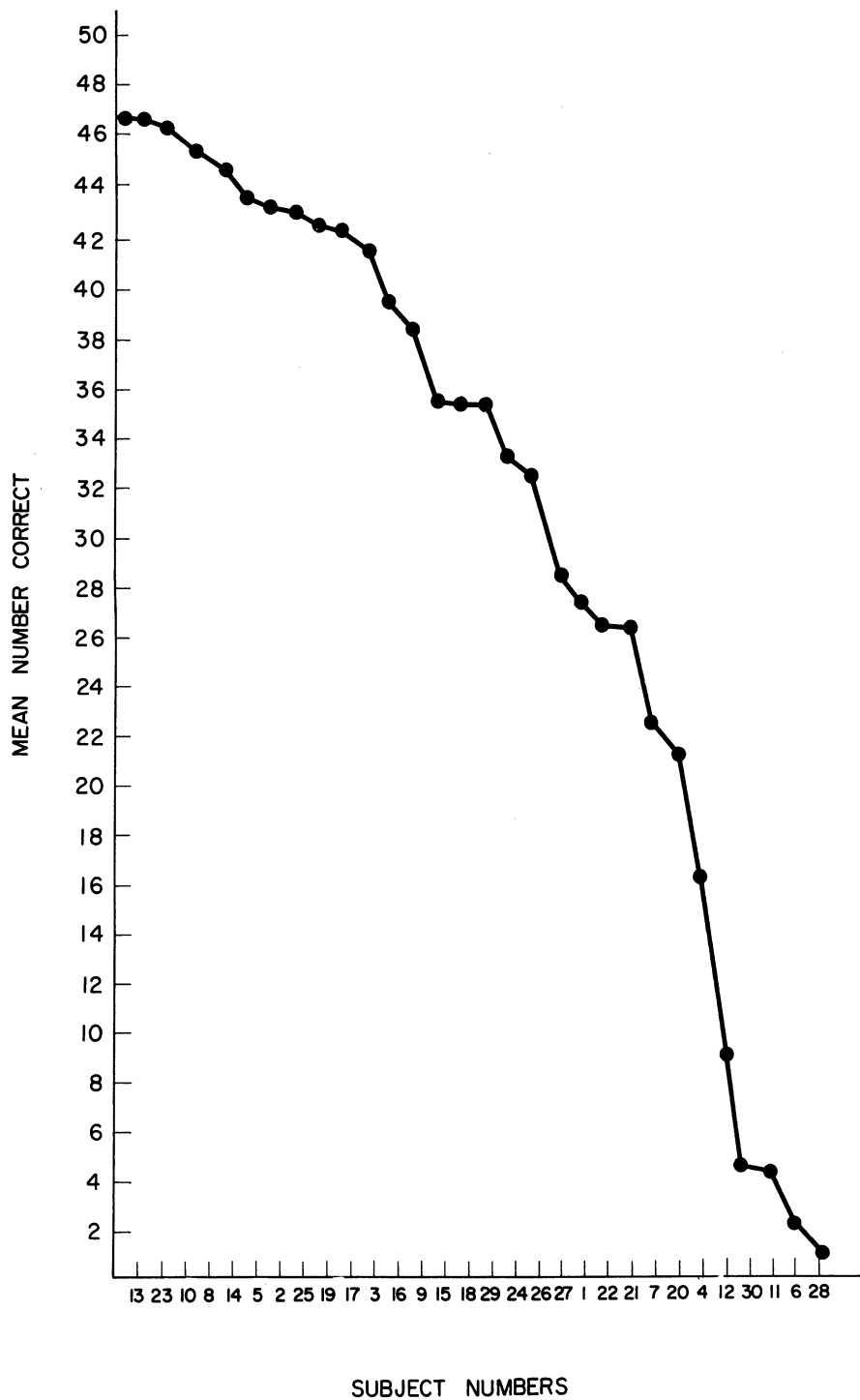


Figure 10. Distribution of mean number of correct listener responses to 30 dysarthric speakers.

Table 15. Degree and range of agreement among listeners responding to dysarthric speakers for Intelligibility Study II.*

Dysarthric speakers											
Number of correct responses	S ₁₈	S ₉	S ₁₅	S ₂₉	S ₆	S ₃	S ₈	S ₁₃	S ₂₇	S ₂₃	S ₁₂
46-50						1	5	13		12	
41-45	3	6	1			13	10	2		3	
36-40	4	4	6	7							
31-35	6	4	7	8		1			2		
26-30	2	1	1						10		
21-25									3		
16-20											
11-15											6
6-10											8
0-5											1

*Cell entries represent the number of listeners who gave correct responses in the ranges indicated. Fifteen listeners responded to each speaker.

Table 15. (cont.) Degree and range of agreement among listeners responding to dysarthric speakers for Intelligibility Study II.

Number of correct responses	Dysarthric speakers									
	S ₁₆	S ₁₁	S ₁₄	S ₁₉	S ₂₄	S ₂₅	S ₂₆	S ₃₀		
46-50			4			2				
41-45	5		10	12		8				
36-40	10		1	3	5	4	4			
31-35					5	1	9			
26-30					5		1			
21-25							1			
16-20										
11-15										
6-10		4						3		
0-5		11						12		

Table 15. (Cont.) Degree and range of agreement among listeners responding to dysarthric speakers for Intelligibility Study II.

Number of correct responses	Dysarthric speakers									
	S ₂₈	S ₂	S ₄	S ₂₁	S ₁₇	S ₂₂	S ₁	S ₂₀	S ₅	S ₇ S ₁₀
46-50		2			2				4	12
41-45		11			8				10	2
36-40		2			5				1	1
31-35				1		4	3			
26-30				8		5	7	3		2
21-25				6		5	5	6		9
16-20			2							4
11-15			7			1		6		
6-10	15									4
0-5										

In most cases, there is very little spread in the range of correct responses for any given speaker. On the basis of these results, we are now exploring several different possible scaling procedures which may be applied to these data.

Each of the 50 words were ranked in order of their difficulty as determined by listener responses. This ranking was compared to that derived for the same population of words based on the item analysis. These rankings are given in Table 16 along with the difference in rank without regard to algebraic sign. A Spearman Rank Correlations was computed to estimate the degree of association between the two sets of ranks. A r_s of .54 was obtained. In order to test the significance of this value for an N of 50, it was converted to a t score. This resulted in a value of $t=4.42$ which is significant beyond the .01 level. Thus, the range of difficulty as well as the difficulty of each word as determined by the original item analysis was confirmed by the new set of listener responses obtained in Intelligibility Study II.

An analysis of listener responses to dysarthrics reading of sentences was also carried out. The purpose of this experiment was (a) to try to determine if sentence material was useful technique for the assessment

Table 16. Rank or order words in revised word list based on number of correct responses and index of difficulty.

WORD	R _I	R _D	d	d ² *
man	1	3.5	2.5	6.25
more	2	22.	20.0	400.00
northwest	3	3.5	.5	.25
inkwell	4.5	14.	9.5	10.25
earthquake	4.5	19	14.5	210.25
schoolboy	6	10	4.0	16.00
buckwheat	7.5	15	7.5	56.25
drawbridge	7.5	27	19.5	380.25
scarecrow	9	20	11.0	121.00
platform	10	17	7.0	49.00
mushroom	11	16	5.0	25.00
playground	12	26	14.0	196.00
woodwork	13	8.5	4.5	20.25
thread	14	37	23.0	529.00
sketch	15	34	29.0	841.00
washboard	16.5	5	11.5	132.25
eggplant	16.5	6.5	10	100.00
charge	18	25	7	49.00
lifeboat	19	2	17	289.00
daybreak	20	11	9	81.00
wildcat	21	6.5	14.5	210.25
cookbook	23	1	22	484.00
tongue	23	18	5	25.00
sledge	23	48	25	625.00
cute	25	23	2	4.00
starlight	26	12.5	13.5	182.25
sleeps	27	44	17	289.00
train	28	41	13	169.00
spice	29	34	15	225.00
twist	30	30	0	0
bounce	31	42	11	121.00
bush	32	38	6	36.00
sheep	33.5	12.5	21	441.00

Table 16. Rank of order words in revised word list based on number of correct responses and index of difficulty (cont.)

WORD	R_I	R_D	d	d^2^*
joke	33.5	36	2.5	6.25
shrug	35	29	6	36.00
duckpond	36	31.5	4.5	20.50
shipwreck	37	8.5	28.5	882.25
with	38	34	4	16.00
shank	39.5	40	.5	.25
chant	39.5	44	3.5	12.25
champ	41	49	8	64.00
bind	42	46.5	13.5	12.25
blush	43	50	7	49.00
scrub	44	21	23.0	529.00
showered	45	44	1	1.00
fused	46	28	18	324.00
dwarf	47	24	23	529.00
barb	48	39	9	81.00
crown	49	31.5	17.5	306.25
grove	50	46.5	3.5	12.25

* R_I = rank based on number of correct identifications.

R_D = rank based on level of difficulty as determined by item analysis.

d = $R_I - R_D$ without algebraic sign.

$\Sigma d^2 = 9214.50$

of intelligibility with dysarthrics and (b) to determine whether there was a high correlation between intelligibility as determined through sentence data and data obtained from listener responses to single words.

Perhaps the greatest difficulty encountered in this part of the research was the development of an appropriate scoring system. The scoring system adopted was based on a count of the number of words correctly identified by the listeners. This permitted a percent correct score to be computed for each speaker and was designated as the Sentence Intelligibility Score (SIS). There was a total of 312 individual words contained in the 40 sentences read by the speakers, and 10 listeners to each speaker. Thus, there were 3120 responses made to each speaker. The SIS for each speaker was obtained by dividing the number of errors by the total number of possible responses.

Normal speakers attained a mean SIS of 97.4% (average intelligibility for all speakers) as compared to 68% for dysarthrics. Tables 17 and 18 present the total number errors made in response to each talker and his SIS. While no dysarthric speaker obtained a SIS as great or greater than a normal, the best dysarthric speaker came within .58% of the poorest normal. However, the normal

Table 17. Number of errors and percent intelligibility scores for sentences based on ten listeners for each normal speaker.

Subject	Number of Errors	Intelligibility Scores in % correct
1N	25	99.19
2N	81	97.40
3N	19	99.39
4N	44	98.58
5N	33	98.94
6N	67	97.85
7N	132	96.02
8N	39	98.75
9N	193	93.94

Table 18. Number of errors and percent intelligibility scores for sentences based on ten listeners for each dysarthric speaker.

Subject	Number of Errors	Intell. Score in % correct
1D	207	93.36
2D	680	78.70
3D	326	89.55
4D	1060	66.03
5D	820	73.71
6D	763	75.50
7D	1082	65.30
8D	1693	45.73
9D	2438	21.85

speaker was not the control for the dysarthric.

On the whole, the dysarthrics were more intelligible using sentence estimates of intelligibility than for single unconnected words. The overall differences in intelligibility between normals and dysarthrics reported in Sentence Intelligibility Study I still hold. There is much less spread of scores among normals as compared to dysarthrics. The range of SIS's for dysarthrics was 71 percentage points (from a low SIS of approximately 22% to a high of approximately 93%) whereas the range of SIS's for normals was about 6 percentage points (from a low SIS of approximately 94% to a high greater than 99%). Thus, the technique employed to evaluate intelligibility with sentences does provide an estimate of the degree of dysarthric impairment with contextual materials which can discriminate among dysarthric speakers.

The nine dysarthrics were ranked on the basis of their SIS's and these ranks were compared to their rankings for intelligibility scores obtained using single words. The Spearman Rank Correlation was employed to test the degree of association between the two sets of ranks. An r_s of .92 was obtained, which for an $N=9$ is significant beyond the .01 level.

It may be concluded from this result that both variables, i.e. SIS and Word Intelligibility Score (WIS) are highly associated in this population. If this finding was shown to hold for other samples, then one might be able to use WIS as a good predictor of overall intelligibility.

An analysis of the types of listener errors observed for the two populations of speakers was carried out. This represents a subjective rather than quantitative approach to the data, and was performed to determine what general patterns could be observed. Several characteristic patterns in listener responses were common to both groups of speakers:

1. The intelligibility of the various parts of speech (i.e. nouns, verbs, adjectives, etc.) were generally equivalent.
2. Position of a word in the sentence had little or no effect on its intelligibility score (i.e. number of correct responses to the word.)
3. Length of word in a sentence as determined by number of syllables had little or no effect on its intelligibility.

Some differences in the general listener response patterns between the two groups of speakers were observed. When responding to dysarthrics, listeners tended to omit sentence segments rather than to respond with "non-words" or to otherwise ignore the semantic rules of English. This was the the case in response

to normal talkers. Here the listeners responded with phonemic substitutions which resulted in "non-words." The substitutions which occurred followed patterns that could have been predicted with other experimental data on perceptual confusions under varying noise conditions. No consistent phonemic substitution pattern was apparent from the listener responses to the dysarthrics. Respondents to normal speakers tended not to omit words as was the case for the respondents to the dysarthrics.

The results of the intelligibility studies suggest rather strongly that it should be possible to develop quantitative measures of some aspects of dysarthric speech which will be reliable and serve as a basis for future research as well as day-to-day clinical evaluations of these patients.

Summary of Results

Results of the acoustic-phonetic analyses of dysarthric speech offer a fuller appreciation of the articulatory and phonatory difficulties which are characteristic of this impairment. They serve as a base from which spectrographic data can be translated to a prediction of what probably occurred during the act of speech production. The descriptions, when summarized across the dysarthrics in the sample, delineates the major features that differentiate these speakers from their normal speaking counterparts. Many of the characteristics have never been adequately described. Application of these descriptions to the design of speech therapy would be the next step in research with dysarthrics, since changes in speech production with therapy should be reflected in spectrograms. This was illustrated in the one case where data was collected during and at the conclusion of speech therapy.

The acoustic-phonetic analysis demonstrates remarkably unique patterns of impairment in each dysarthric subject. These idiosyncratic patterns, even when reduced to features common to most dysarthrics,

suggest that there is no clearly definable relation between locus and extent of lesion and the speech impairment it produces. Much more needs to be known regarding the neurology of articulation and phonation as motor-sensory acts in the normal before inferences can be made about the dysarthric.

Data obtained from spectrograms are only suggestive of errors listeners will make in response to dysarthric speech. Apparently, the average listener is able to ignore and, in fact, probably does not perceive, some of the more subtle acoustic alterations which characterize dysarthric speech. There are, however, many instances in which it is possible to predict with precision the confusions listeners will make. Further study of these occurrences appears to be warranted.

The findings presented in this report indicate that objectivity in the assessment of dysarthric intelligibility can be achieved. There is a high degree of association between intelligibility scores obtained from responses to words and to sentences. Further, the degree of association between estimates of impairment given by clinicians (i.e. moderate, mild, severe) evaluating the speakers and the scores based on listener responses is not very great. Nor does there

appear any direct relation between neurological factors and reduction of intelligibility as measured in this research.

Differences between dysarthrics and normals on all intelligibility measures was so great that no statistical test of the difference was needed.

Both the initial and revised tests of intelligibility employed yield reliable scores which can be used to evaluate degree of dysarthric impairment. Results obtained from these experiments suggest that it should be possible to develop scales for evaluating the intelligibility of dysarthric speech. In addition, improvement in intelligibility following speech therapy should be reflected in intelligibility scores. It is our contention that the revised word list used in Intelligibility Study II can be developed into a useful evaluative tool for the speech clinician.

Perceptual errors made by listeners further reveal the idiosyncratic nature of dysarthria. However, there does appear to be some relation between amount of error and complexity of the articulatory act necessary for accurate production. The type of confusion made by listeners can often be predicted from the sound spectrograms.

The results of our investigations lead us to conclude that the techniques of acoustic-phonetics, when combined with studies of speech intelligibility, are valuable tools for research on dysarthria and for speech pathology in general. Application of these methods can yield a greater degree of objectivity in the description of dysarthrics and provide a basis for a quantitative assessment which would be of both theoretic and clinical value. However, much research is still necessary before these goals can be achieved.

List of Publications and Papers Presented at Meetings

Papers Presented at Meetings

- Tikofsky, R.S., I. Lehiste and R.P. Tikofsky. Phonetic Characteristics of Dysarthria. Amer. Speech and Hearing Assoc. Chicago, 1961.
- I. Lehiste, R.S. Tikofsky, and R.P. Tikofsky. An Acoustic Description of Dysarthric Speech. Acoustical Soc. of Amer. Cincinnati, 1961.
- R.S. Tikofsky, I. Lehiste, R.P. Tikofsky. A Study of the Intelligibility of Dysarthric Speech. Acoustical Soc. of Amer. Cincinnati, 1961.
- R.P. Tikofsky, T.J. Glatcke, and G.L. Reynolds. Intelligibility of Dysarthric Speech. Amer. Speech and Hearing Assoc. Chicago 1963
- T.J. Glatcke, R.P. Tikofsky. Listener Confusions of Dysarthric Speech. American Speech and Hearing Association. Chicago, 1963.
- R.P. Tikofsky. Assessing the Intelligibility of Dysarthric Speech. Invited Address. Houston Speech and Hearing Center, Houston, 1965.

Publications (including abstracts of papers given at meetings)

- Tikofsky, R.S., Lehiste, I. and Tikofsky, R.P., Phonetic characteristics of dysarthria. ASHA, 3, 368 (1961) abs.
- Lehiste, I., Tikofsky, R.S. and Tikofsky, R.P., An acoustic description of dysarthric speech. J. Acous. Soc. Amer., 33, 1677 (1961) abs.
- Tikofsky, R.S., Lehiste, I. and Tikofsky, R.P., A study of the intelligibility of dysarthric speech. J. Acous. Soc. Amer., 33, 1677 (1961) abs.
- Tikofsky, R.P., Glatcke, T.J., and Reynolds, G.L., The intelligibility of dysarthric speech. ASHA, 5 , 806 (1963) abs.

Tikofsky, R.S. and Tikofsky, R.P., Intelligibility measures of dysarthric speech. J. Speech Hearing Res., 7 325-333 (1964)

Lehiste, I., Some acoustic characteristics of dysarthric speech. Bibliotheca Phonetica, Fasc. 2, 1-124 (1965)

Tikofsky, R.S., Glattkke, T.J. and Tikofsky, R.P., Listener confusions in response to dysarthric speech. Submitted to Folia Phoniatria for publication.

Appendix I

Instructions to Listeners

in

Intelligibility Study I

Appendix I

The instructions to the listeners were:

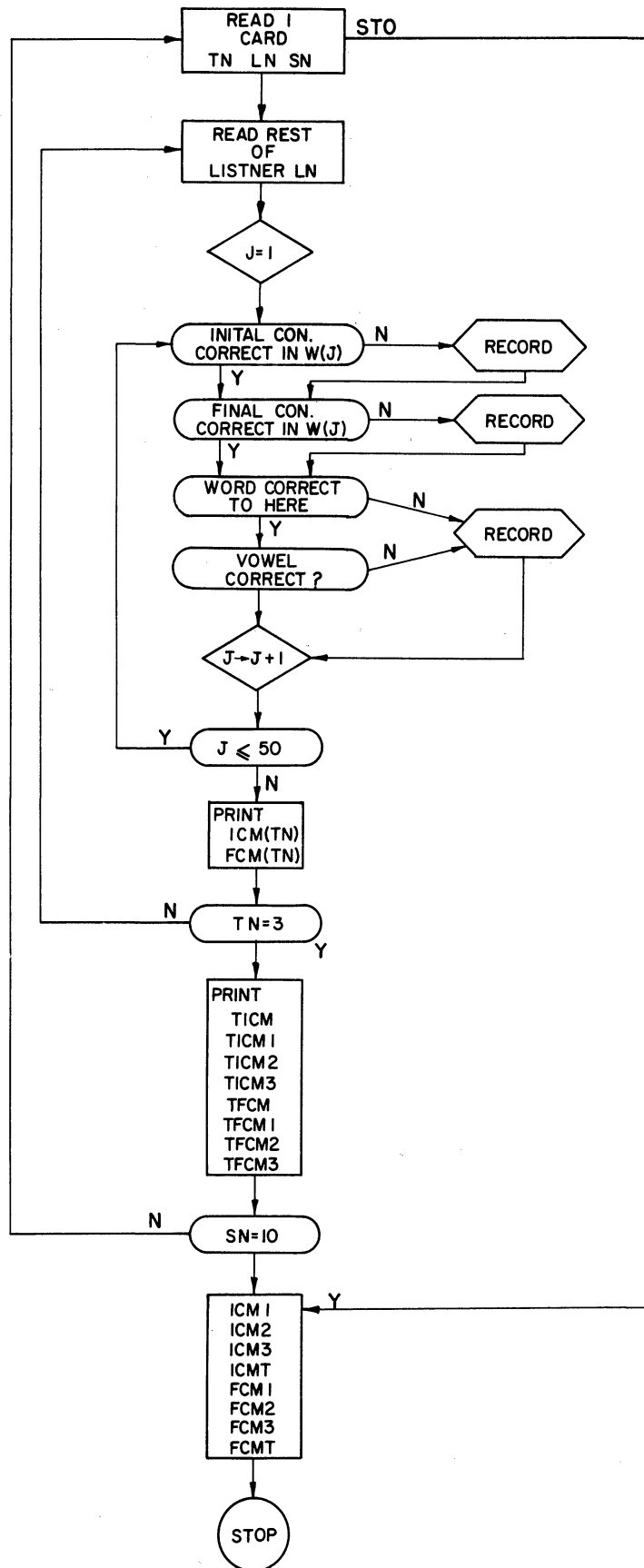
You are about to hear three lists of words. Please write down the word you think you hear on the sheets provided. If you do not understand a word, draw a line in the space alongside the appropriate number. Ready? List number 1.

Additional instructions were played for the listeners before the second and third tests were presented:

List number _____. Remember, if you do not understand a word, draw a line in the space opposite the appropriate number. Ready? List number ____.

Appendix II

Flow Diagram for Computer Program
To Analyze Listener Responses to
CNC Words and Initial and Final Confusion
Matrices for Dysarthrics



TOTAL INITIAL CONFUSION MATRIX FOR ALL TAPES

DR. AND MRS. RONALD TIKOFSKY ARE PROUD TO PRESENT THE FOLLOWING RESULTS

P	B	T	D	K	G	M	N	F	V	TH	S	Z	SH	R	L	CH	J*	H	W	WH	Y	BLANK	OTHER
P	799	104	8	0	4	2	1	0	15	0	0	0	0	10	1	0	0	26	1	5	0	84	20
B	134	566	3	7	2	2	4	0	8	5	0	0	0	0	0	1	0	0	4	0	0	69	5
T	5	5606	40	24	14	0	0	1	0	0	0	0	0	0	4	1	0	29	0	0	0	50	31
D	1	866	547	0	10	0	0	3	4	24	0	0	0	0	2	29	8	0	0	0	0	83	25
K	5	0	33	2644	55	0	0	0	0	0	1	0	0	2	1	1	4	2	0	0	0	49	11
G	0	1	6	28	141	315	0	1	0	0	0	0	0	0	0	0	4	0	0	0	0	39	5
M	25	19	0	0	1	0	671	13	3	0	0	0	0	19	2	0	0	2	16	0	0	32	7
N	0	2	2	0	0	2	11	467	0	2	1	0	0	0	6	11	0	4	3	0	1	25	3
F	35	18	1	1	1	0	1	0	604	11	0	15	0	1	5	0	0	6	29	5	0	64	13
V	0	19	3	0	1	1	0	1	61	132	3	2	0	0	11	0	0	1	2	0	0	23	10
S	1	0	0	0	1	0	0	0	2	0	1	753	9	0	16	3	1	3	0	0	0	18	2
SH	0	0	18	7	0	0	0	0	1	0	0	47	0	402	0	18	8	1	0	0	0	26	12
R	0	0	0	0	0	0	0	0	2	0	0	1	0	0	828	18	0	10	9	41	0	107	64
L	4	17	0	0	0	1	5	11	3	1	12	0	0	0	49	591	0	2	32	0	0	44	38
CH	0	0	57	0	2	0	0	0	0	1	9	0	8	0	0	156	26	0	0	0	0	9	2
J*	0	0	85	38	4	3	0	0	1	0	0	0	0	0	2	3	316	1	1	1	3	52	30
H	13	4	0	0	1	6	1	0	3	1	1	0	0	16	4	0	0	649	0	1	0	104	6
W	0	4	0	0	1	0	0	0	1	0	0	0	0	18	5	0	0	5	672	34	0	58	12
WH	2	0	0	0	0	0	0	0	0	0	0	0	0	16	5	0	0	6	28	197	0	12	4
Y	0	1	0	0	1	0	0	3	0	0	0	0	0	5	10	0	9	67	0	0	121	50	3

TOTAL FINAL CONFUSION MATRIX FOR ALL TAPES

DR. AND MRS. RONALD TIKOFFSKY ARE PROUD TO PRESENT THE FOLLOWING RESULTS

P	B	T	D	K	G	M	N	NG	V	F	TH	S	Z	SH	G*	R	L	CH	J*	BLANK/OTHER
P 681	25	22	2	3	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	40 34 (80) .840
B 20 171	4	13	0	4	4	0	0	0	0	1	1	0	0	0	0	4	0	0	0	33 15 (27) .633
T 2 01078	98	7	3	0	2	0	0	0	0	0	0	0	1	0	0	0	3	1	0	107 48 (135) .799
D 2 5 113 814	1	4	1	2	1	3	0	2	0	1	0	1	0	0	4	0	0	0	0	94 33 (108) .753
K 10 0 32	3 874	31	0	0	0	0	0	0	0	0	8	2	0	0	0	0	0	1	0	91 28 (108) .810
G 1 0 36	26 157 218	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	95 5 (54) .410
M 0 1 0	0 2 0	0 696	32	4	1	0	0	0	0	0	0	0	0	0	0	2	1	0	0	61 10 (60) .859
N 0 0 0	0 0 0	0 1031273	115	1	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	105 21 (130) .765
NG 0 0 0	0 0 0	0 12 53 175	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5 25 (210)
V 1 0 2	9 0 0	0 1 0 224	5	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18 4 (210)
F 2 0 0	0 0 1	6 0 0	0 0 0	7 214	1	7	0	4	0	0	0	0	0	0	0	0	0	0	0	28 0 (210)
IH 0 0 19	1 0 0	0 0 1	0 1 0 1	9 305 113	8	11	0	0	0	0	0	0	0	0	0	0	0	0	0	42 30 (510)
S 0 0 7	1 0 0	0 0 0	0 1 17	4 676	7	3	0	0	0	0	0	0	0	0	0	0	0	3	0	39 52 (910)
Z 0 0 0	0 0 0	0 0 1	0 2 6	0 33 456	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29 13 (510)
SH 0 0 0	0 0 0	0 0 0	0 0 0	0 1 31	0 204	1	0	0	0	0	0	0	0	0	0	0	0	3	4	15 11 (270)
G* 0 0 0	0 1 0	0 0 0	0 0 0	3 0 13 84	0 129	0	0	0	0	0	0	0	0	0	0	0	0	0	3	34 3 (210)
R 0 0 3	0 4 1	0 0 0	0 6 0	0 3 2	1 0 0	0 697	12	0	0	0	0	0	0	0	0	0	0	0	0	61 20 (910)
L 0 0 3	2 3 5	9 0 0	0 0 0	0 0 0	0 0 0	0 52 924	0	0	0	0	0	0	0	0	0	0	0	0	0	322 21 (1350)
CH 0 0 9	2 0 0	0 0 0	0 0 0	0 0 0	0 26	1 2	0	0	0	0	0	0	0	0	0	0	0	170	16	18 26 (270)
J* 0 0 62	6 0 0	0 0 0	0 0 0	2 1	0 0	0 1	0	0	0	0	0	0	0	0	0	0	0	31	119	40 8 (270)

Appendix III

Preliminary Report on the Study of the Acoustic
Characteristics of Dysarthric Speech

Appendix III

Preliminary report on the study of the acoustic characteristics of dysarthric speech

July 21, 1960

Ilse Lehiste

The following remarks are intended to provide a first approximation of what should eventually grow into an acoustic description of dysarthric speech. The findings are based on a study of two individuals; some of the symptoms occurred in both sets of data, while others seemed to be associated with one speaker only. It remains to be ascertained to what extent the symptoms are characteristic of dysarthric speech in general.

The findings are presented under five general headings; neither the number of classification nor their order are significant at the present moment.

1. Lack of coordination between phonation and articulation. This lack of coordination was very general in the speech of both patients. It was manifested in various ways. A rather common way of manifestation was the late onset of voicing during initial voiced resonants, such as /l/ /r/ /m/ /n/. In most instances, a voiceless period was followed by a brief voiced period; however, instances occurred where the total duration of the resonant was voiceless, and voicing started abruptly with the onset

of the vowel. In final position, cessation of voicing during a final voiced resonant was also observed, but in final position this need not be a symptom of dysarthria.

A very general symptom is the devoicing of voiced plosives in both initial and final position. In initial position it was noticed that the secondary characteristics of voiceless and voiced plosives were also often confused: the voiceless plosives were often articulated with very scant aspiration, whereas the supposedly voiced plosives were sometimes followed by an aspiration that was comparable to that used by the speaker with voiceless initial plosives. It is suggested that the problem of phonemic distinctions be investigated in these cases. In other words, listening tests are suggested to check whether the patient distinguishes p/b, t/d, k/g in his own speech and more generally in the speech of other speakers of the same dialect.

A further interesting problem is presented by the presence of noise during the gaps of the plosives. A purely mechanical problem may have caused this; however, the possibility might be considered that during the articulation of some of the plosives the velum may have been lowered (nasalization is often present

throughout the utterance), and that the noise represents an emission of air through the nose, with a certain amount of friction produced during this emission. The acoustic records are insufficient for determining this at the moment.

In addition, the lack of coordination between onset of phonation and articulatory movements suggests that we may find some evidence of "voiceless vibration." A recent French investigation has shown that in the case of two dysarthric patients, vocal fold vibration (without emission of sound) took place during the hold of voiceless plosives. It is suggested that we repeat the experiment (the instrumentation appears to be fairly simple) to determine whether the kind of lack of coordination that we have noticed can indeed be studied by such techniques.

2. Difficulty in performing controlled movements.

The acoustic patterns show a great deal of irregularity in the articulation of such consonants and syllable nuclei that involve movements in which the rate of articulatory change is significant. Initial and final /r/ is a particularly defective sound; the dialect background of the speakers lets us expect a retroflexed Midwestern type of /r/, which cannot be found in the speech of the patients. Initial /w/ is practically

always absent; initial /y/ is often articulated as /i/, with a slow change from the /i/ position to that of the following vowel.

Another characteristic is the occasional occurrence of extremely rapid changes in the total formant pattern, without any measurable transitions between the steady state positions. Such jerky patterns suggest an inability to maintain a steady configuration for an extended period of time.

In a previous study of syllable nuclei it was found that a tense-lax contrast could be associated with the relative duration of the target and the off-glide. It is suggested that the material be studied to determine whether this distinction is maintained in dysarthric speech. Subjectively, it is noticed that the tense-lax distinction appears to be absent in the initial plosives; it is hoped that a technique may be developed for measuring the relative intensity of the explosions to check this observation (the continuous amplitude display is insufficient, since the energy of the explosions may be expected to appear at frequencies higher than 1500 cps).

3. Difficulty in kinesthetic monitoring of point and manner of articulation. It was observed that the speakers

confused stops and fricatives at the same point of articulation. This occurred both initially and finally. In final position, it appeared that fricatives were more often substituted for plosives; in initial position, a labiodental plosive or affricate was substituted for /v/. The final /l/ appeared to be articulated without closure on several occasions; however, the acoustic records cannot be interpreted unambiguously at this moment.

A further symptom that was present quite prominently in the speech of one of the patients was the apparent inability to select points of articulation between the alveolar ridge and the velum to provide necessary distinctions between t, d, w and k g ŋ. It appeared that the speaker was fairly certain at the extremes of the possible points of articulation the labial series and some of the velar allophones of /k/ were properly produced --, but that he was quite uncertain about intermediate position. Both the /t/ series and certain of the allophones of /k/ appeared to be articulated at a general middle range, so that the word gull sounded like dull and get sounded like gyet. The speaker repeated some of these utterances until he produced an acceptable form; a change in the formant transitions reflects

the successive approximations to the "correct" point of articulation. Occasionally both point and manner of articulation were affected: successive productions of hut had first a final voiced velar fricative, then a voiced velar stop, a voiced cluster gd, and finally a voiceless t. The speaker was able to understand the word he heard, but seemed to have difficulty in monitoring his own production.

4. The problem of clusters needs to be investigated more fully. It appears that some of the clusters offer greater problems than others. An order of difficulty should be established. There may be an upper limit in the number of consonants that may constitute the cluster; it needs to be investigated which member of the cluster is dropped in such instances, and whether this is determined by the position within the cluster or by the class of consonants involved. The possibility should be checked that no regular patterns may appear in these instances.

5. Further problems to investigate concern the suprasegmental components of speech: problems of intonation (one of the speakers uses rising inflections in every utterance), problems of timing; stress; distribution of intonation contours over individual words and larger

utterances. It may be advisable to limit the present investigation to a study of the segmental components of speech. The test material devised for the study was mainly oriented toward the investigation of segmental sounds.

6. An intelligibility study of the speech of the patients is presently being carried out by other members of the research group.

Appendix IV

An Acoustic Description of Dysarthric Speech

An Acoustic Description of Dysarthric Speech

Ilse Lehisté, R.S. Tikofsky, and R.P. Tikofsky

Paper presented at the 62nd meeting of the
Acoustical Society of America in Cincinnati on Nov. 11, 1961

For the past two years, a group of us at The University of Michigan have been engaged in an acoustic-phonetic study of dysarthric speech. Our ten dysarthric subjects receive a neurological examination, their speech problems are diagnosed by a speech pathologist, an acoustic analysis of 160 test words produced by each subject is carried out, and an intelligibility study of the dysarthric speech provides data for correlating the results of the acoustic analysis with listener reactions. Some results of the intelligibility study will be reported separately; the present paper offers examples of the types of dysarthric symptoms that can be best observed by spectrographic analysis.

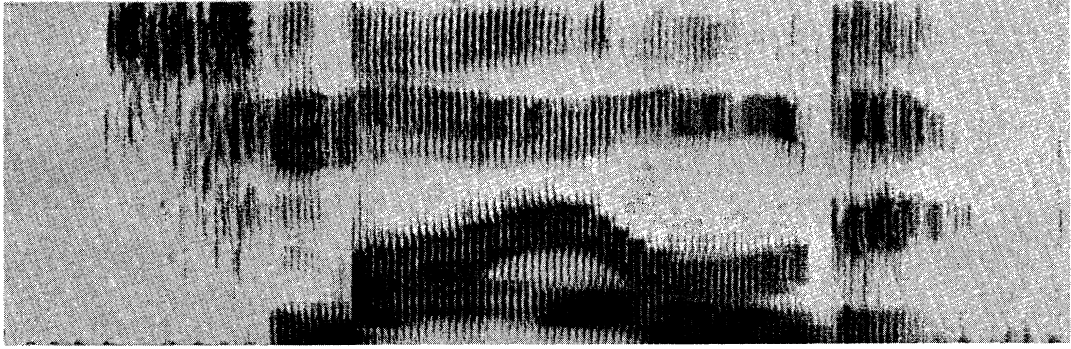
We have classified the symptoms according to their acoustic characteristics. Some of them occur in the speech of all dysarthric subjects; others occur in the material produced by smaller subgroups of the population, and we are in the process of comparing the subgroupings determined by the neurological diagnosis of the patients. Usually several symptoms occur in each test word; therefore, I cannot present illustrations of each symptom separately, which would also require much more space than is available

However, the following slides contain a representative collection. Slide 1. One of the general characteristics of dysarthric speech is a lack of coordination between articulation, phonation, and nasalization. The first slide contains broad band spectrograms of the word smiled, produced by a normal speaker (the first in the series), and two dysarthric subjects. If you observe the segment corresponding to /m/, you will notice that it is fully voiced in the speech of the normal subject. One of the dysarthric speakers produces a voiceless nasal, which becomes voiced about three centiseconds before the onset of the vowel; the second dysarthric speaker produces an entirely voiceless segment. The transitions from this segment to the following syllable nucleus indicate that although both the features of voicing and nasality are lost, the bilabial articulation has remained.

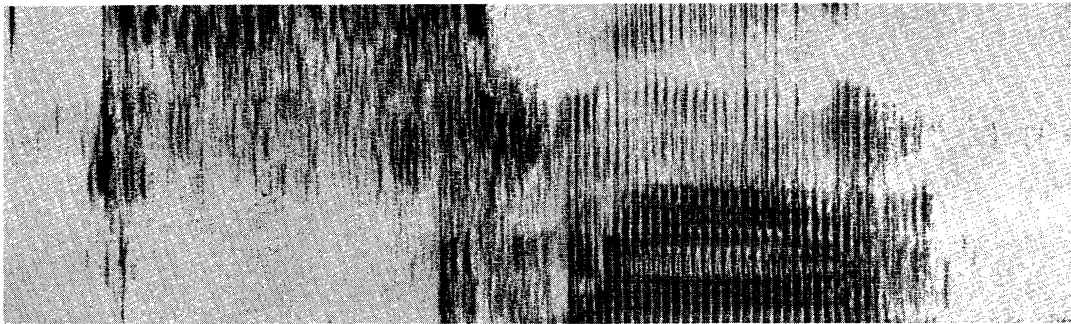
Slide 2 contains spectrograms of the words gap and pike, spoken by a normal and a dysarthric subject. The contrast between a voiced and a voiceless initial plosive is quite apparent in the normal articulation. The dysarthric subject produces a voiceless plosive in each case; the aspiration is 8 csec for gap and 20 csec for pike. This type of neutralization of contrast between voiced and voiceless initial plosives is also a fairly general characteristic, although it does not always take this form: there are instances where voiceless plosives lose their aspiration, so that the leveling is in the other direction.

Slide 3 presents a still different form in which the lack of coordination between phonation and articulation may appear.

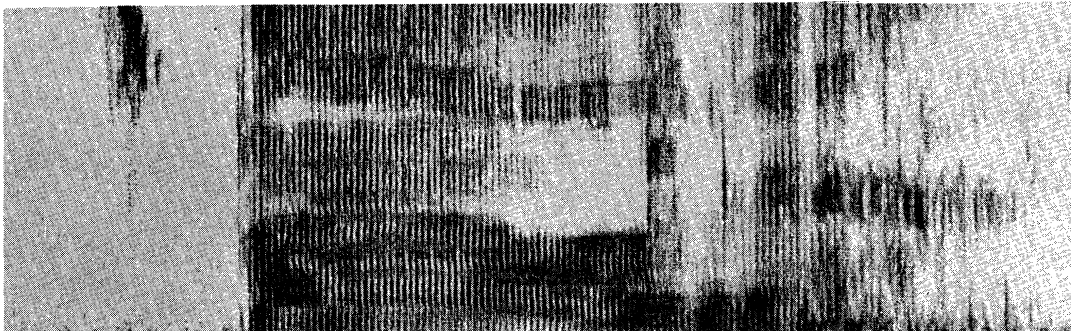
N



S6



S8



SMILED

Slide 1



SIO

GAP



SIO

PIKE



N

GAP



N

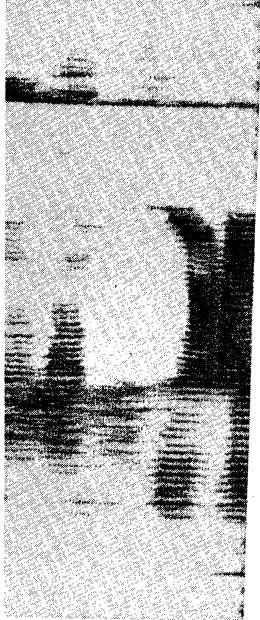
PIKE

Slide 2



N

GULL



N

VOTE



N

LAKE



S9b

GULL



S9a

VOTE



S9a

LAKE

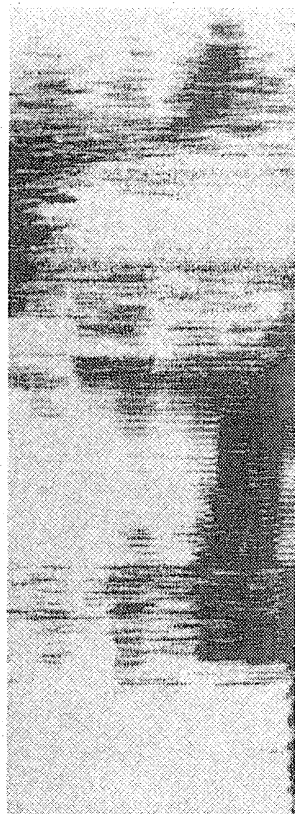
Slide 3

The three words gull, vote, and lake are presented on the slide, pronounced by a normal speaker and a dysarthric speaker. Subject 9 was recorded twice, once before therapy and again after a year of speech therapy. In the word gull, the dysarthric subject is producing a voiceless plosive, followed by a laryngealized onset of the vowel. Three broad bands appear preceding the vowel onset; in a narrow band spectrogram, these appear as harmonics rather than formants. The auditory impression is that of an implosive consonant; if the harmonics represent a high-pitched sound, there is no auditory impression of voicing. In the word vote the segment /v/ is voiceless. The auditory impression is of a voiceless /v/ rather than /f/. It may be interesting to note here that out of 32 listeners who judged that word, 13 identified the word vote correctly, while 19 substituted words beginning with /f/. A voiceless /v/ is not part of the English sound system, so the listeners identify it with one of the two phonetically most similar sounds. The final /t/ in this word contains noise in formant-like bands, and the release is heavily affricated. The auditory impression is of a voiceless plosive.

The word lake starts with a voiceless /l/; again a sound that does not occur normally in English in initial position. The substitutions were mostly words beginning with the voiceless interdental fricative. The final /k/ presents a series of problems. The auditory impression is that of a voiceless plosive with a heavily affricated release. Examination of the spectrogram suggest that there are actually four segments in the /k/; first voice, then voiceless with formant-like bars, then voiced again, and lastly voiceless. The formant-like bars are similar to those observed in initial position in gull. We

of problems. The auditory impression is that of a voiceless plosive with a heavily affricated release. Examination of the spectrogram suggests that there are actually four segments in the /k/: first voice, then voiceless with formant-like bars, then voiced again, and lastly voiceless. The formant-like bars are similar to those observed in initial position in gull. We have not solved the problem of the intermittent voicing during the plosive; this is one reason why we are planning to extend this study to an investigation of the phonatory patterns of dysarthric speakers. Several of the other speakers also produce this noise during what should be plosive gaps.

Slide 4 introduces several other symptoms. This slide contains spectrograms of four utterances of the word bounce. The utterance in the left top corner was produced by a normal speaker. The lower spectrogram on the left hand side represents a pronunciation without an initial plosive segment; the auditory impression is that of a glottal stop. The transition from the syllable nucleus toward the final cluster is voiceless; final /n/ is completely voiceless. and the whole syllable nucleus is laryngealized. The speaker whose utterance is shown in the right top hand corner had a voiceless /b/, followed by a segment of breathy phonation. A brief voiced /n/ is followed by a voiceless /n/ and an aspirated /s/. The lower right spectrogram contains an utterance by a speaker who has inserted an extra segment between the voiceless initial /b/ and the syllable nucleus. The auditory impression is of an /r/; however, the important



S1



S3



N



S5

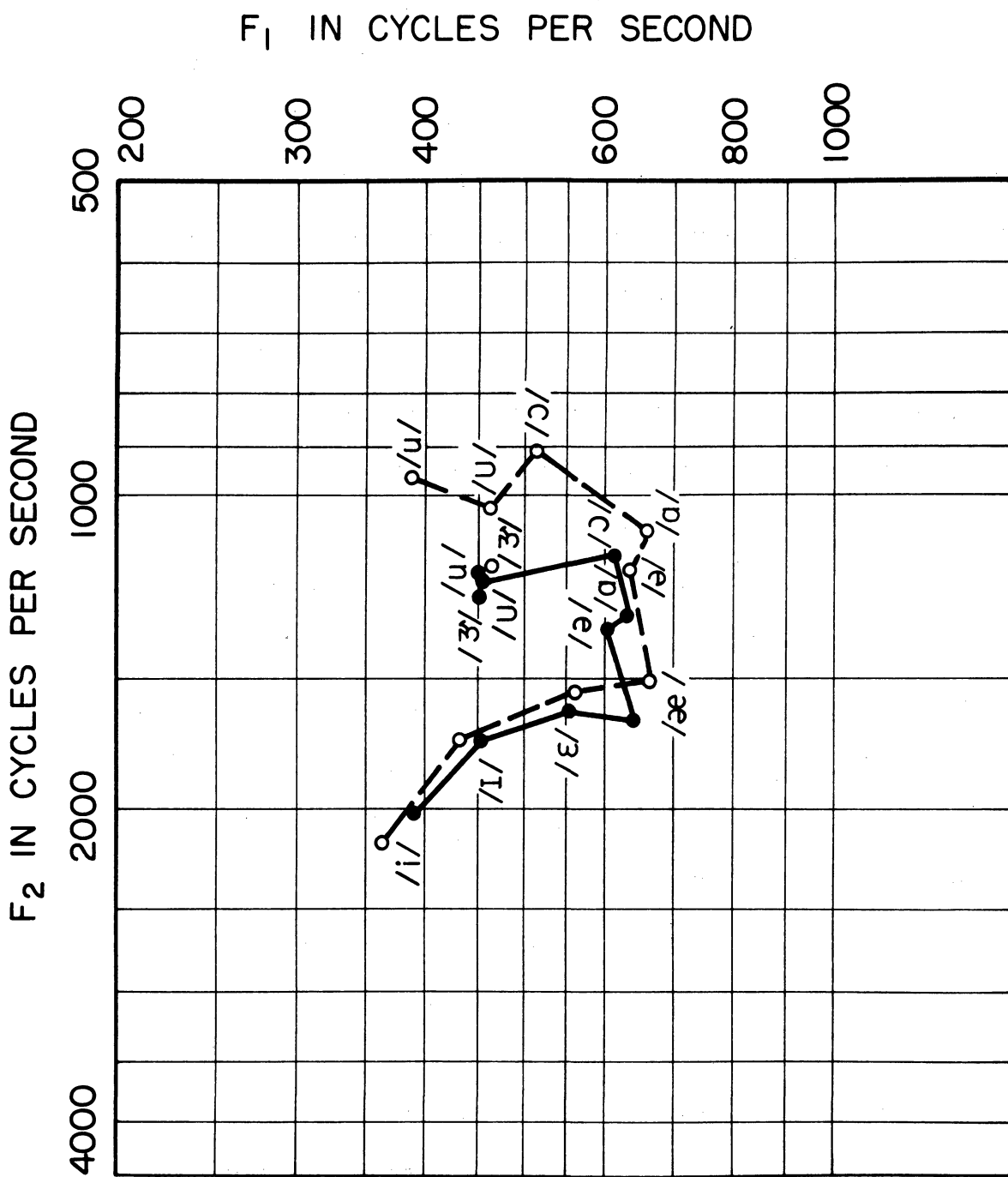
BOUNCE

slide 4

BOUNCE

feature to notice here is the abrupt change from the /r/ position to the /a/ position. There is no transition between the /r/ segment and the vocalic segment; the articulatory movement producing this change in the resonances must have been very rapid indeed. This type of rapid change in formant structure is another feature of dysarthric speech that occurs fairly consistently in the speech of all dysarthrics. The abrupt change of phonation pattern, with resultant breathy segments and laryngealized segments, is also a general feature; however, laryngealization has been observed also in normal speakers and does not by itself constitute a symptom.

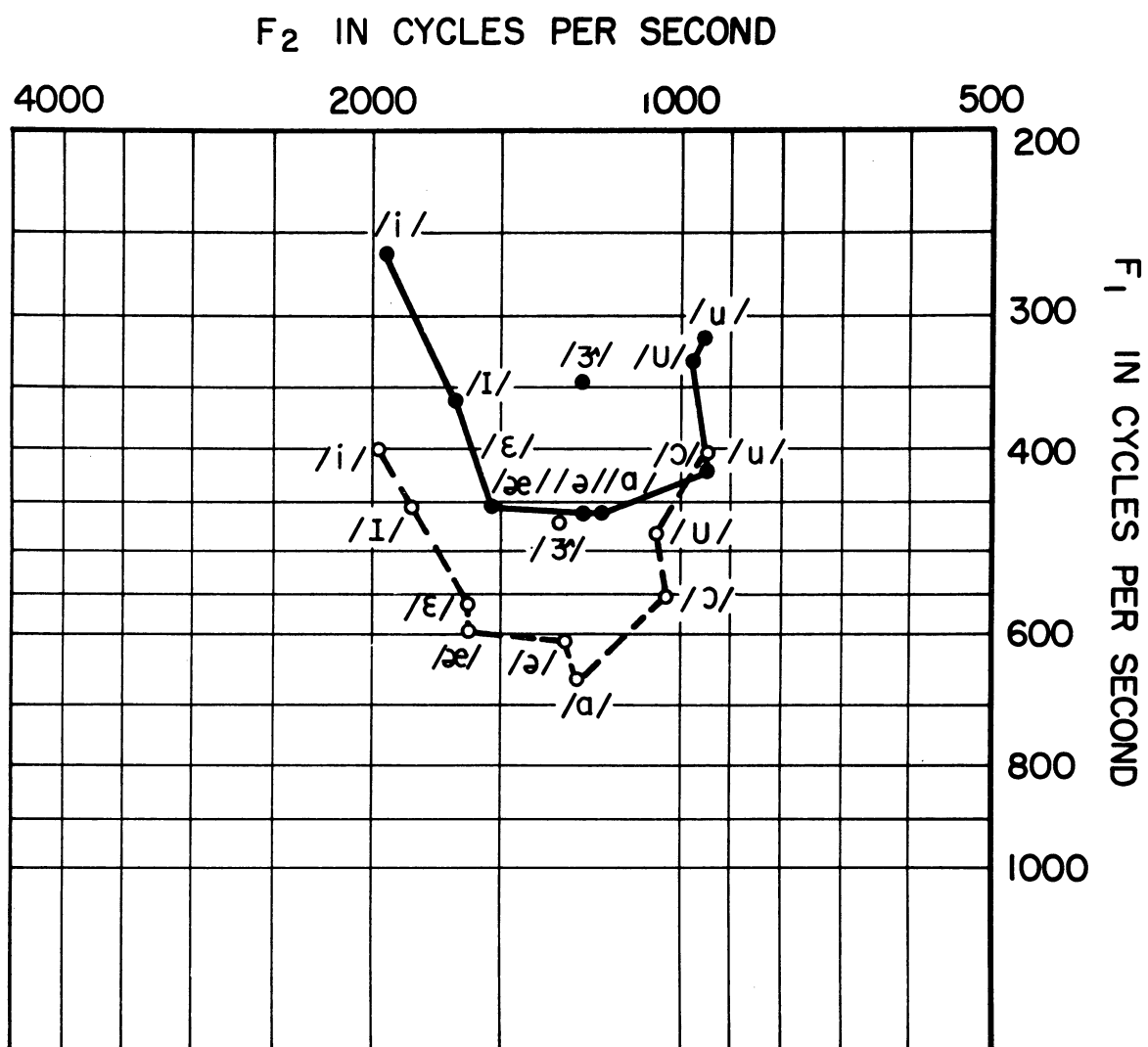
There are other dysarthric symptoms which appear on spectrograms and which we expect to describe in a more systematic fashion when the report is presented in final form. I would like to show now some of the results of the analysis of the syllable nuclei. Slide 5 shows two acoustical vowel diagrams. The solid line connects points representing average formant positions of ten vowels produced by a dysarthric subject, the dashed line connects points representing the same syllable nuclei produced by a normal speaker. It is apparent that the series of front vowels are quite comparable; the back vowels, however, are markedly different. The second formant is evidently much higher for the dysarthric speaker than for the normal speaker; /ə/ and /a/ are both



central and so close that a contrast based on formant structure is probably absent in this subject's speech.

Slide 6. The next slide shows two vowel diagrams representing the vowels used by a dysarthric speaker before and after therapy. The solid line indicates the average formant positions before therapy, the dashed line connects points indicating average formant positions in the same set of words after the patient had received speech therapy for a year. This latter diagram is very similar to the normal diagram which was included on the previous slide. It is evident that during the first recording most vowels had very small first formant values, so that the whole pattern was somewhat shifted up in addition to several other distortions.

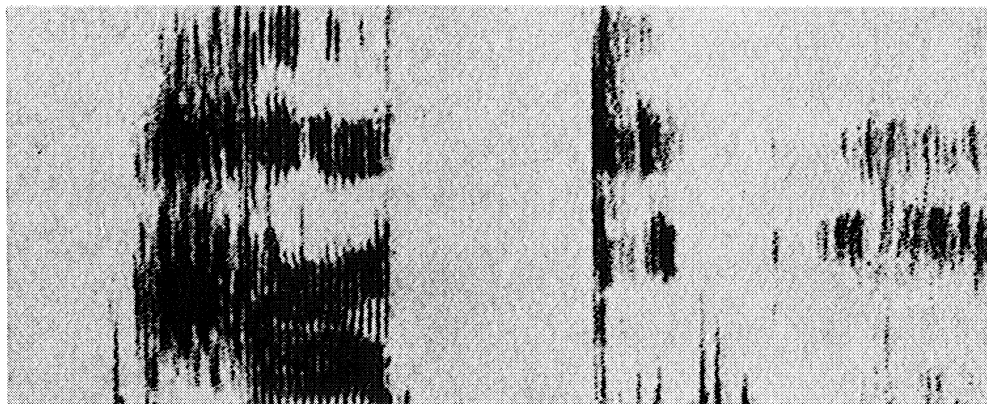
This study of dysarthric speech has provided us with many new insights. We are planning to carry through a componential analysis of the significant phonetic features, to state to what degree they may vary independently, and attempt to relate these findings to the diagnosed central nervous system impairment of the speakers. We are also studying the reactions of the listeners to the distorted speech, and are correlating the substitutions in the responses with the acoustically analyzed symptoms. Knowledge of the linguistic system of the language, coupled with the available acoustic data, often makes it possible to predict



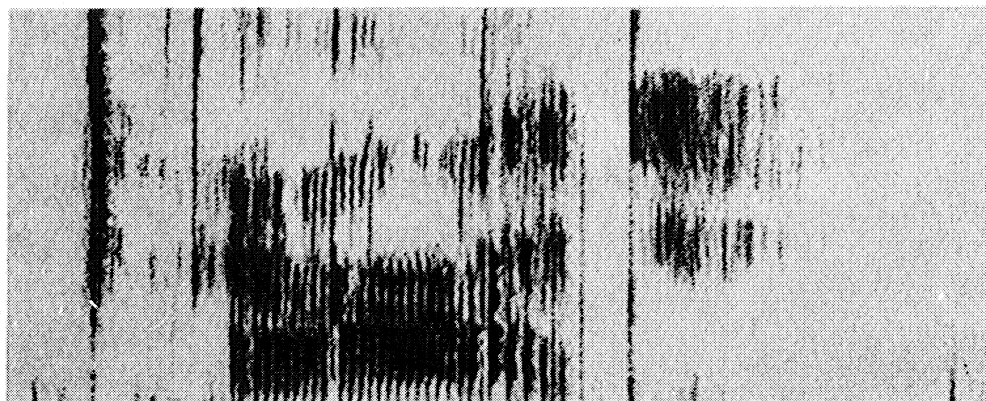
the substitutions. An illustration is presented on Slide 7. This slide contains a normal and two dysarthric productions of the word hut. The normal pronunciation involves a short syllable nucleus and a long plosive gap. Subject 5 pronounced the word with a syllable nucleus that was more than twice as long. The final plosive, although voiceless, is considerably shorter than the voiceless plosive in the normal utterance. The formant positions are approximately what one would expect. In English, the long vowel most similar to the vowel in hut is /a/. The short voiceless plosive resembles a final /d/, which is very often devoiced in normal speech. It may be predicted that the sequence of the syllable nucleus and final consonant will be identified as odd. The first consonant in the dysarthric production is a voiced uvular fricative. Since the listeners may be expected to identify it with the phonetically most similar sound in English, their responses might inform us which of the English sounds appears most similar to a voiced uvular fricative.

The group of 30 listeners produced no correct responses; there were two omissions. Words containing an /a/ as syllable nucleus in normal speech were substituted in 26 instances: the final consonant was heard as /d/ in 23 instances. In four instances the voiceless plosive was heard as /t/. The two

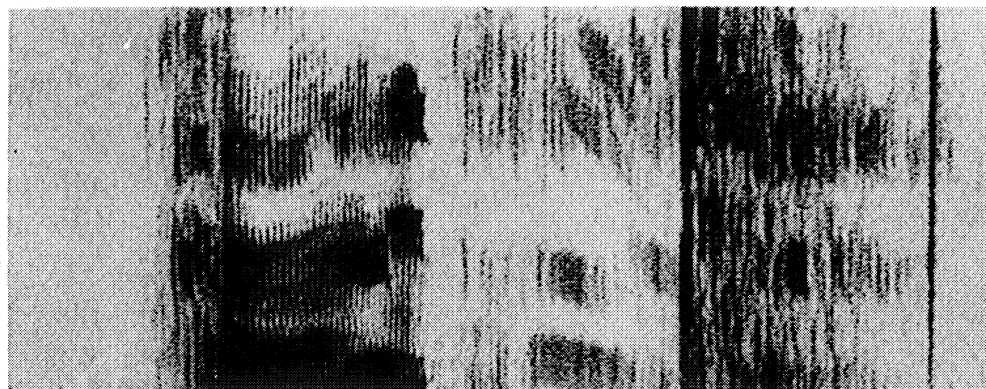
N



S5



S9a



HUT

most frequent substitutions were odd, with 11 occurrences, and rod, with 8 occurrences. There were four occurrences of the word god and two of rot. The uvular fricative was thus completely ignored in 11 instances. Those who heard the word as god, probably reacted primarily to the place of articulation cues present in the uvular fricative; the majority of those who identified the initial consonant at all evidently felt that the uvular voiced fricative was most similar to an English /r/.

In the third spectrogram on the slide the syllable nucleus is neither long nor short, and the first and third formants are much lower than we would expect for a shwa. Nevertheless, 14 listeners identified the word correctly; there were ten substitutions of heart and hurt, indicating that an /r/-colored vowel was heard. Seven other substitutions involved /a/ (hot and lot). Thus in 17 instances the syllable nucleus was identified with a long vowel. This suggests that the length of the syllable nucleus probably constitutes a distinctive characteristic in English; when an intermediate length is produced, about half of the listeners hear a short vowel, whereas the other half identify the sound with a long vowel. Information of this type contributes also toward our understanding of the language.

Appendix V

Phonetic Characteristics of Dysarthria

PHONETIC CHARACTERISTICS OF DYSARTHRIA

Presented at

The American Speech and Hearing Association
1961

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From the Communication Sciences Laboratory; Speech Clinic, Department of Speech of the College of Literature, Sciences and the Arts; and the Department of Neurology of The University of Michigan Medical Center, The University of Michigan.

This investigation was supported by a PHS research grant, number B-2221, from the National Institutes of Health, Division of Neurological Diseases and Blindness, Public Health Services.

The present paper represents an initial report of the first two years study of the phonetic characteristics of dysarthria through the use of acoustic and instrumental phonetic techniques. The approach was selected in the hope that it will provide a more objective basis for the classification of some types of dysarthric speech. A further aim is to relate the obtained characteristics to the neurologic difficulty producing the dysarthric symptoms. A study of the intelligibility of the dysarthric speakers was also made.

The test material developed for the study consists of

four lists: 1. a set of fifty CNC words (consonant-syllable nucleus-consonant); 2. a set of sixty monosyllabic words containing initial and final consonant clusters; 3. a set of fifty spondees; and 4. a set of forty brief sentences. The lists were recorded by ten dysarthric speakers in the Communication Sciences Laboratory or the Neurology Research Laboratory at the University of Michigan Medical Center.

The recordings were subjected to spectrographic analysis using the Bell Telephone Sound Spectrograph at the Communication Sciences Laboratory. The sound spectrograph is an electronic device which converts an accoustical signal into visual form, where the relative distribution of energy among the various frequencies of the spectrum appears as a function of time. Thus 160 spectrograms were made for each of the subjects, or a total of 1600 spectrograms for the dysarthric population. The spectrographic analysis of the sentences has not yet been completed.

To study the intelligibility of the dysarthric speech, listening tapes were constructed from the original recordings. Three such listening tapes were made for each subject; on each of the tapes the sequence of the lists appeared in a different order. Each listener was required to write the word that he thought the dysarthric uttered. No clues were present to aid the listener. Ten listeners were used for each listening tape for each dysarthric subject; a total of 49,600 responses forms the basis of the intelligibility

study, The listeners were students at The University of Michigan and members of the Communication Sciences Laboratory and the Speech Clinic who were not participants in this research.

The essential biographical and clinical data for each of the ten dysarthric subjects are presented in the first slide. All of the subjects were native to the midwest or came to the middle west prior to the time they might have developed fixed dialect patterns. One of the subjects was recorded early in the course of speech therapy and re-recorded sometime after his discharge from therapy. All of the subjects were given complete neurologic examinations by the members of the staff of the Department of Neurology of The University of Michigan Medical Center. The dysarthrics were all males between the ages of 20 and 68, and represent a variety of occupational, socio-economic and educational backgrounds. One normal native mid-western speaker was also recorded.

The spectrographic analysis was designed to permit a detailed investigation of each of the utterances produced by the dysarthric speakers, as well as to provide data for comparisons between dysarthrics. In order to make the desired analysis the following measurements were made on the spectrograms obtained for each utterance made by the subject:

DYSARTHRIC SUBJECTS

Subject Number	Age	Educational Level	Occupation	Neurological Diagnosis	Etiology	Date of Onset	Qualitative Judgment of Severity	Amount of Speech Therapy
1	42	M. D.	M. D.	Posttraumatic Brain and Cerebellar Deficit	Auto Accident	6/19/58	Moderate	2 mos.
2	65	8th grade	Salesman	Progressive Bulbar Palsy	Unknown	11/60	Severe	None
3	68	8th grade	Farmer	C. V. A.	Embolism	7/59	Severe	None
4	38	College (3 yrs.)	Sales Engineer	Closed Head Injury	Auto Accident	7/59	Mild-Moderate	2 wks.
5	35	10th grade	Factory-Laborer	Postencephalitic	Acute Encephalitis	1/60	Severe	None
6	20	College (2 yrs.)	Student	Posttraumatic Encephalopathy	Auto Accident	8/2/58	Moderate-Severe	3 yrs.
7	47	12th grade	Oilier	Unilateral Parkinsons	Encephalitis (?)	1936	Severe	None
8	38	High School	Unemployed	Fredric's Ataxia	Unknown	1929	Moderate	None
9	25	College (2 1/2 yrs.)	In service at time of accident	Posttraumatic Brain Stem Damage	Auto Accident	12/20/57	Moderate	1 1/2 yrs.
10	52	B. A.	President of own Corporation	C. V. A.	C. V. A.	4/22/58	Severe	3 yrs.

Slide 1

1. Position of the three formants in the syllable nucleus for all words at the target or steady state of the vowel.
2. The duration of the syllable nucleus in the CNC words.
3. Formant position at the point of transition from the initial consonant to the syllable nucleus and at the point of transition from the syllable nucleus to the final consonant.
4. The duration of the transitions.
5. The duration of the initial and final consonants.
6. The formant positions within the resonant consonants as well as the energy concentrations in the fricatives and in the plosive releases were also measured.

Intelligibility was measured in terms of the number of words correctly identified by a normal listener. Several intelligibility measures were available for study. The measures which were analyzed for the present paper were not concerned with the individual words but rather with overall performance in terms of dysarthrics, lists and orders. The following scores were computed from the original intelligibility data:

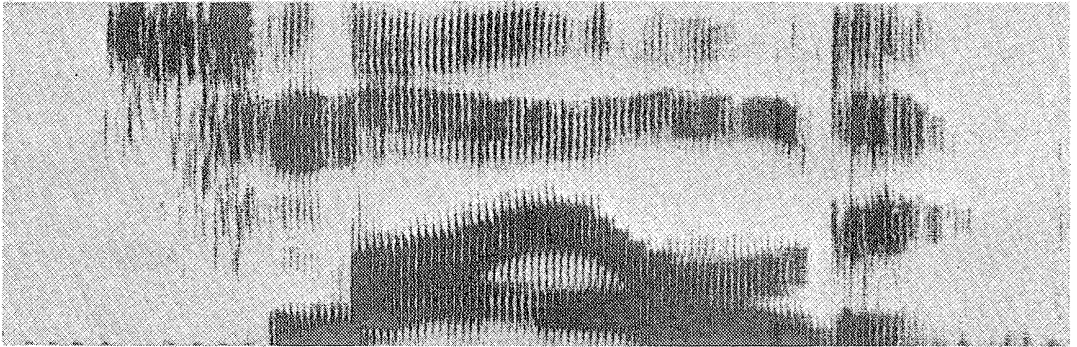
1. A total intelligibility score. This score represents the total number of correct responses made by all of the listeners for a particular dysarthric subject.
2. A total order intelligibility score. This score

represents the total number of correct responses made by all of the listeners for a particular dysarthric subject for a given list without regard to order.

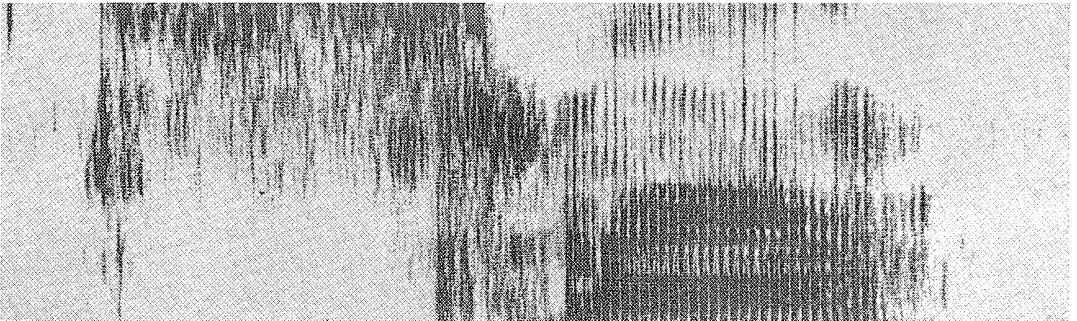
4. A total list by order intelligibility score. This score represents the total number of correct responses made by all of the listeners for a particular dysarthric subject for a given list in a given order.

The spectrographic analysis of the test words has revealed several deviations from the expected normal patterns. Certain of the deviations occur in the speech of all dysarthric subjects; others occur in the material produced by smaller subgroups of the population, and we are in the process of comparing the subgroupings determined by the neurological diagnosis of the subjects with subgroupings determined on the basis of acoustically described symptoms. A few examples of the types of findings are presented on the following slides. Slide 2 contains three broad-band spectrograms of the word smiled from the cluster list. The first spectrogram represents a normal utterance. Notice the relatively short /s/ segment and the fact that /m/ is fully voiced. The following syllable nucleus contains two clearly defined targets, with smooth transitions between the targets; the final cluster consists of a long, voiced, velarized /l/, and a brief voiced /d/

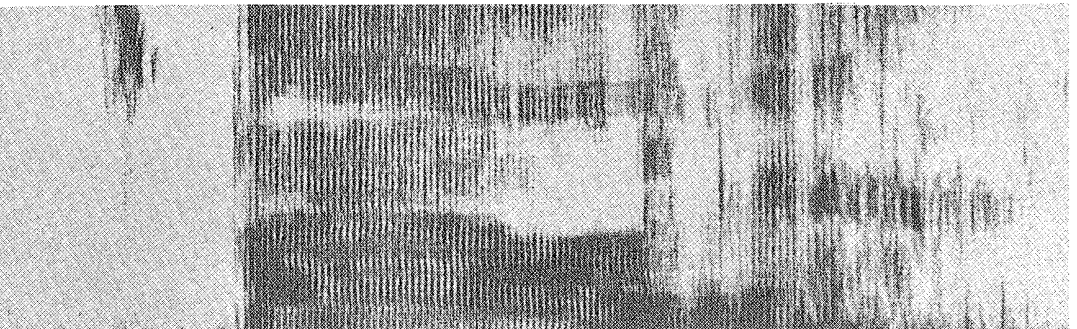
N



S6



S8



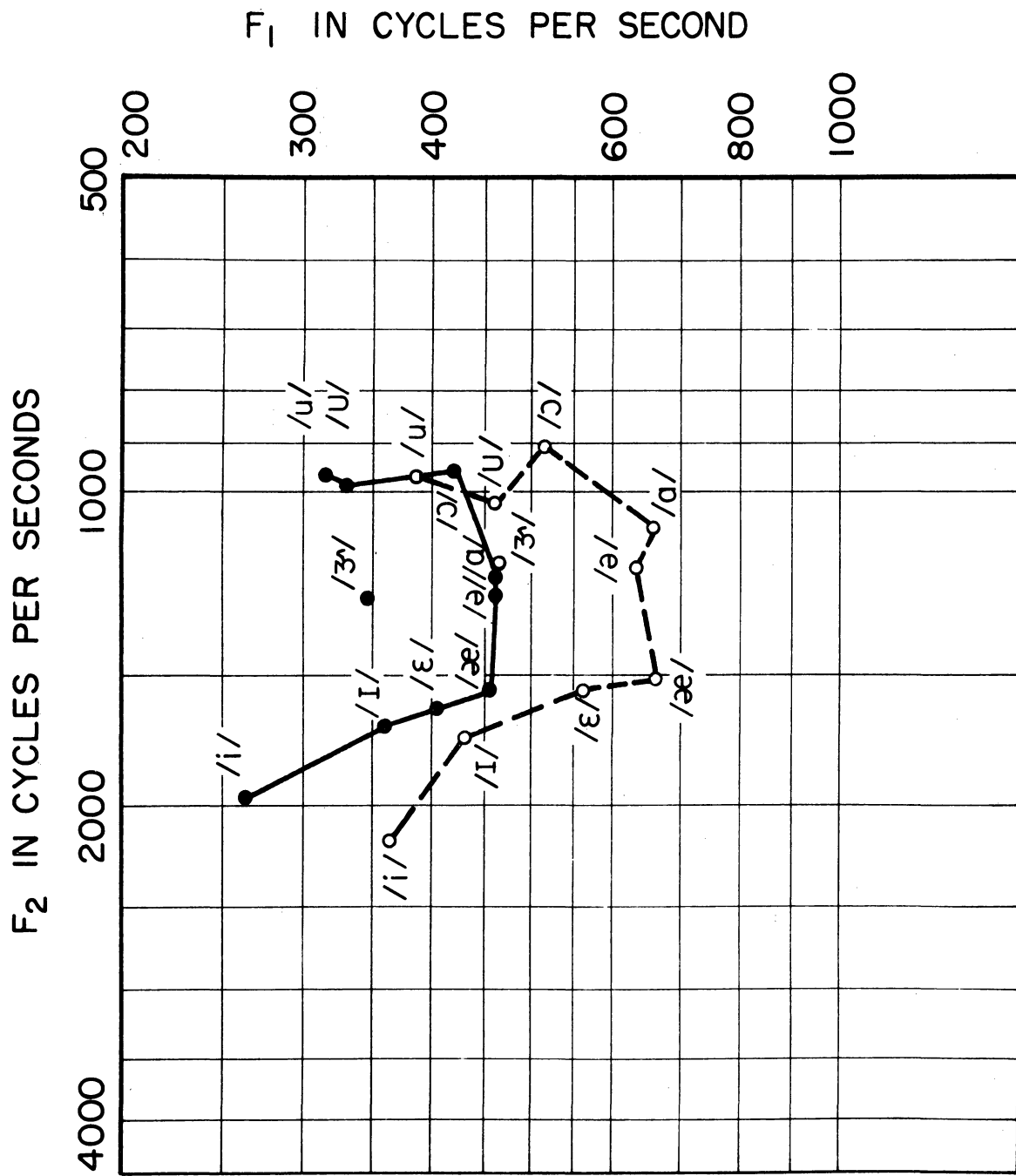
SMILED

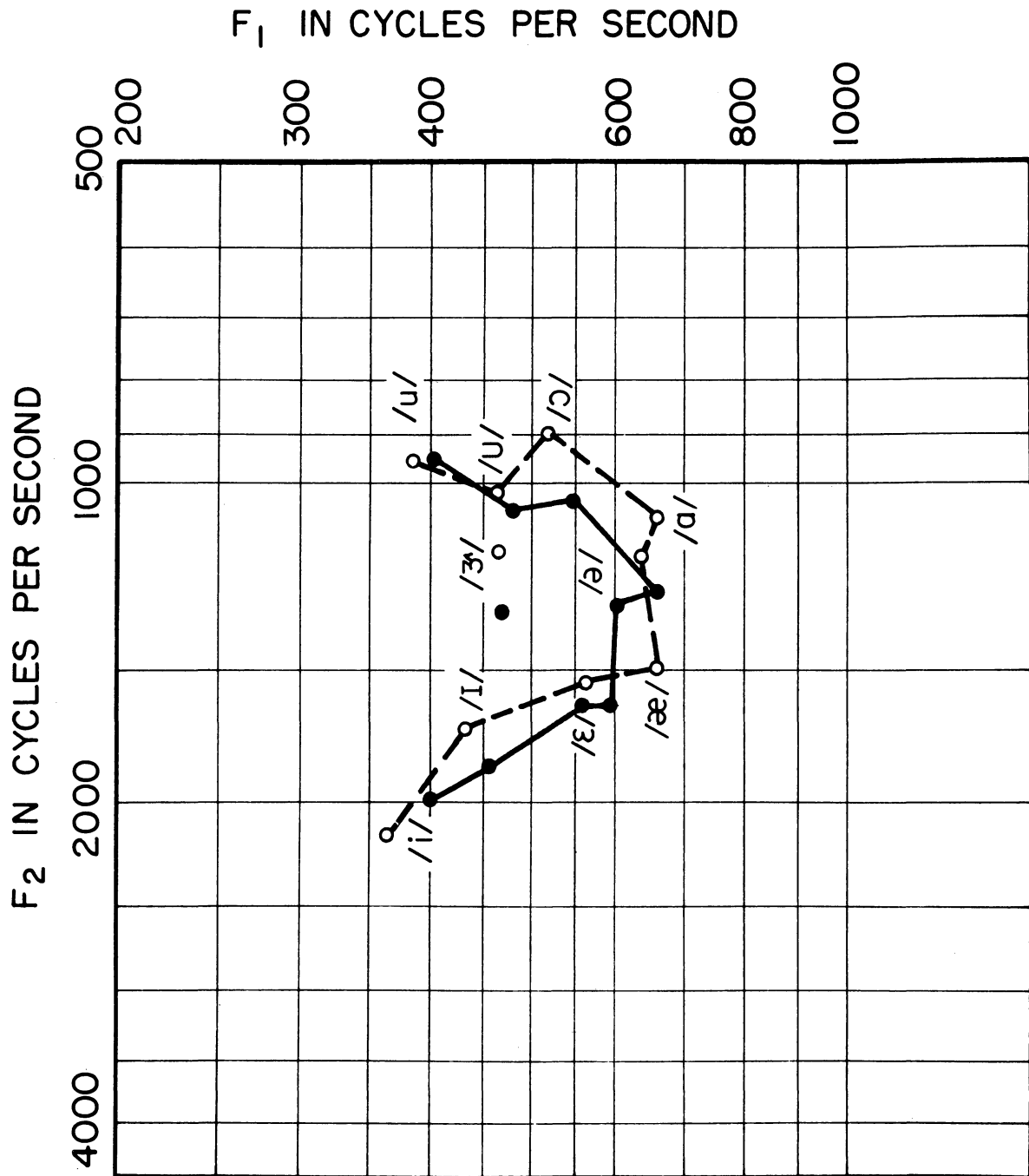
with a voiced release. The second spectrogram, produced by Subject 6, has an extra-long /s/ segment with a low cut-off frequency, which produces the auditory impression /ʃ/. This sibilant-like segment is followed by aspiration, which is followed by a voiceless /m/. However, not the total duration of /m/ is devoiced; voicing starts before the /m/ is released, so that a very brief voiced nasal segment occurs before the velar closure takes place. The syllable nucleus has only one target, /a/. The second element of the diphthong is omitted; the final /l/ becomes voiceless during its production, and there is no final /d/. All thirty listeners identified this word as smile, omitting the final /d/ whose absence was also noted on the spectrogram, but evidently having no question about the initial /s/ plus /m/ sequence. The significant contribution of the spectrographic approach is the discovery that the /m/ and /l/ were partly voiceless. The lack of coordination between phonation and articulation, illustrated on this spectrogram, is one of the general characteristics of dysarthric speech. It appears in the speech of all our subjects, although it takes different forms with different dysarthric speakers. The third spectrogram, representing the pronunciation of the same word by Subject 8, shows a similar lack of coordination between articulation, phonation, and nasalization. In this

instance a very brief /s/ segment is followed by an entirely voiceless segment in place of the expected voiced nasal /m/. The low F1 and F2 transitions to the syllable nucleus cause an auditory impression of a voiceless /^b/ and suggest that although both the features of voicing and nasality are lost, the bilabial articulation has remained. In the following syllable nucleus there are two segments, but the second segment is not an /i/, which would be reflected in a rise of the second formant. The second formant is lowered instead, suggesting a rounded back vowel as the second component of the diphthong. A short voiced /l/ is followed by a voiced /d/, a long voiced release, and a long aspiration. In spite of the complete voicelessness and velar closure, 16 out of 30 listeners heard the word as intended. Five listeners gave no answer; there were nine substitutions of the words spoiled, spelled, and sprawled. This points out the fact that listeners react to words rather than separate sounds: the word most similar to the distorted stimulus word is recorded, and the exact nature of the distortion is disregarded. Sounds that are alien to the phonemic system of the listeners are identified with the phonetically most similar sounds in a given distribution.

The objectivity provided by spectrographic analysis enables the analyst to overcome the bias introduced by his own linguistic background.

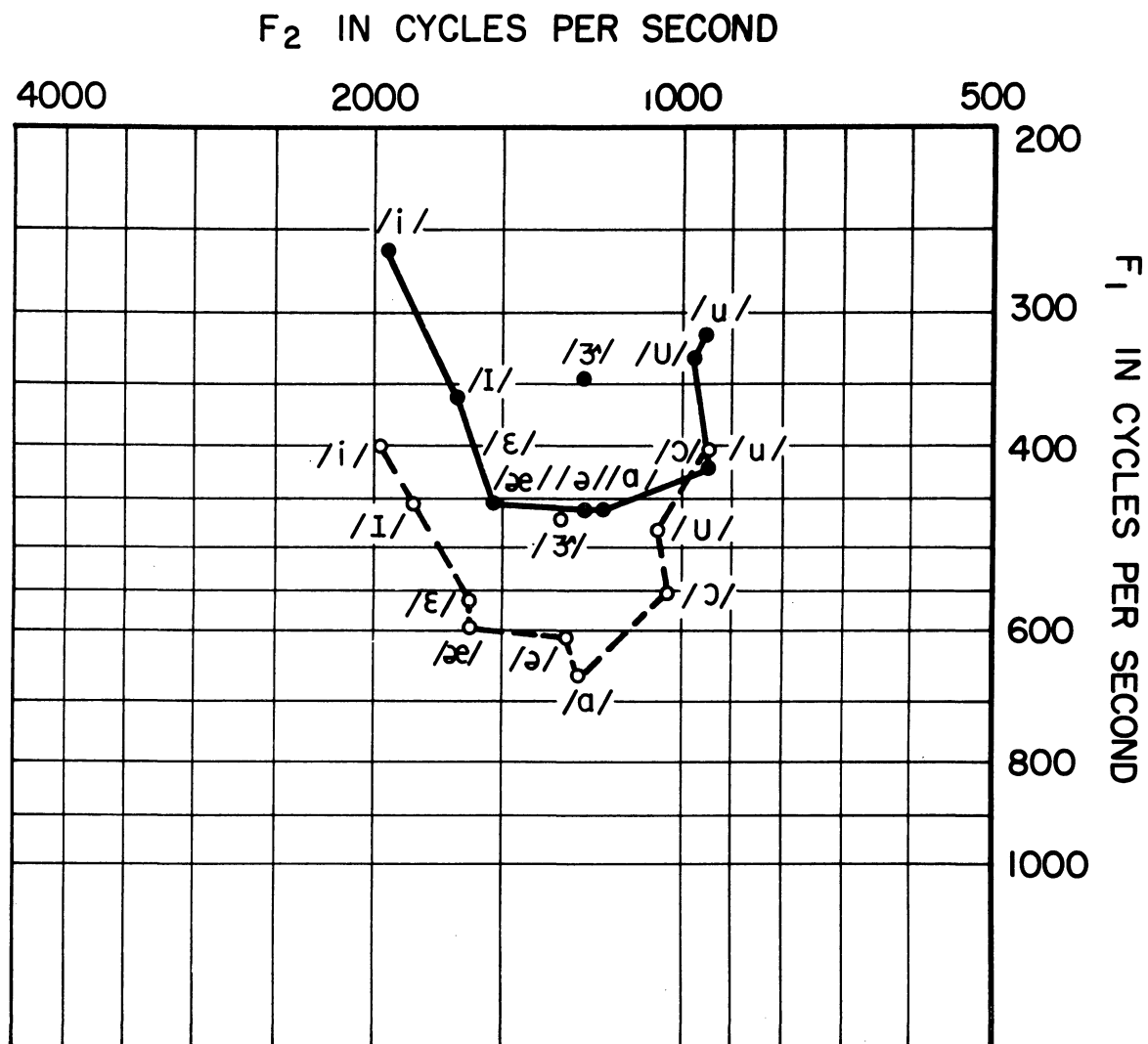
The spectrographic data have been employed in different kinds of analyses, some of which will be illustrated on the following three slides. This slide shows two acoustical vowel diagrams. The solid line connects points averaged from occurrences of ten syllable nuclei in the speech of Subject 9a. The dashed line connects comparable points derived from materials produced by a normal speaker. It is apparent that the first formant in the speech of the dysarthric subject has a consistently smaller value than expected; as a result, the whole pattern is shifted up and somewhat squeezed in the horizontal direction. The points representing occurrences of /u/ and /U/ are too close, suggesting that a contrast based on formant positions is unlikely in the speech of this subject. The same applies to /ə/ and /a/; both pairs are clearly distinct in the normal pattern. Slide 3 shows the same data for the same subject, after a year's therapy. The normal pattern is the same as before. It is obvious that the vowel pattern is now much more similar to the normal pattern; the differences are probably no greater than





between normals. Slide 5 shows a comparison between the patterns for the same subject before and after therapy. Of course, this type of vowel diagram does not bring out one characteristic deviation of dysarthric speech from normal speech: within each set of points representing realizations of one syllable nucleus, the dispersion is much greater for a dysarthric speaker than for a normal speaker. Nevertheless, it appears that there was considerable improvement in the vowel production. It should be added, however, that the production of consonants deviated even more from the expected normal pattern at the time when therapy was ended than before therapy, and the results of the intelligibility study indicate that in spite of the improvement in the vowel pattern, the speaker was less intelligible when the second recording was made. It appears thus that consonants carry a greater amount of the intelligibility information than vowels, and that vowel analysis is probably a less sensitive tool for judging the prospective intelligibility than consonant analysis.

The statistical analysis of the intelligibility data yields information which has both clinical as well as theoretic significance. An analysis of variance revealed that there was a significant difference between the dys-



Slide 5

arthric speakers. There was an obvious difference between the most intelligible dysarthric and the normal speaker. However, the overall analysis failed to show any significant differences for lists or order. At first glance, it would appear that it would not be necessary to be concerned about the selection of a test word list by the diagnostician when he tries to determine the articulatory and phonatory characteristics presented by the dysarthric. It would also seem that if more than one list of words were used in the evaluation it would not matter in which order the diagnostician heard the lists. Such a situation would reduce the amount of time necessary to evaluate the dysarthric's speech. However, when the statistical analysis is carried further so as to examine the interactions between subjects and lists, subjects and order, order and lists, and subjects, lists and orders we find that these interactions are all highly significant. Only when we consider the entire population of dysarthrics is it possible to ignore the lists or order effects. This means that if we are conducting experiments in which we are not concerned with the individual it is possible to use just one list for the study. However, if we are more interested in studying the individual, it becomes necessary to use more than one list and it is necessary to take into consideration the order in which the lists are heard. We can expect to find that our interpretation of the symptoms varies according to

the material selected for analysis and the order in which we make this analysis for a given speaker. Thus it is possible to miss some pertinent information if the influence of these interactions is not taken into account.

In addition to the statistical analysis described above, we also ranked the subjects in terms of intelligibility based on listener responses. This procedure confirmed the results of the statistical analysis. It also suggests that it should be possible to develop scaling procedures for determining the severity of dysarthria on the basis of intelligibility scores.

The research reported in this paper suggests that some new approaches to the diagnostic evaluation of dysarthria are needed. It points out the lack of precision of the commonly used terms such as "substitutions," "distortions," and "ommissions" for an adequate description of the dysarthric's articulatory effort, and demonstrates that it is possible to derive more precise descriptions through spectrographic analysis. These analyses plus information gleaned from intelligibility data will permit the development of methods of analysis and classification leading to more precise diagnosis and better understanding of the dysarthric's disability, which in turn, will result in improved therapeutic techniques.

Appendix VI

A Study of the Intelligibility of Dysarthric Speech

A STUDY OF THE INTELLIGIBILITY OF DYSARTHRIC SPEECH

presented at

Meetings of Acoustical Society of America

Ronald S. Tikofsky, Ph.D.

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Rita P. Tikofsky, M.S.

From the Communication Sciences Laboratory; Speech Clinic, Department of Speech of the College of Literature, Sciences and the Arts; and the Department of Neurology of The University of Michigan Medical Center, The University of Michigan.

This investigation was supported by a PHS research grant, number B-2221, from the National Institutes of Health, Division of Neurological Diseases and Blindness, Public Health Services.

The speech scientist and speech pathologist are both interested in the communicative act. Both are therefore concerned with problems relating to the efficient transmission of signals or information between speaker and listener. In the typical model information can be lost at several points: at the input the ear of the listener, at the output the speaker's articulatory act, or in the signal itself due to some external interference such as filtering. In most of the studies reported at these meetings the alterations in the signals used to study intelligibility have been experimentally induced. In the present paper the alterations

of the signals are the result of the subject's inability to produce normal articulatory and phonatory patterns because of damage to the nervous system which has impaired his ability to use the mechanism properly. Speech disorders of this type are classified as dysarthrias. This paper reports an initial investigation of the intelligibility of a population of dysarthric speakers based on listener responses.

The dysarthric population was composed of ten male subjects ranging in age from 20 to 69. The essential biographical and clinical data for these subjects are presented in Slide 1. Subject 9 was recorded early in the course of speech therapy and then some months after his discharge. All of the subjects were native to the middle west or came to the middle west prior to the time they might have developed fixed dialect patterns. One non-dysarthric male native midwestern speaker was also recorded.

The test material developed for the study consists of four lists: 1. a set of fifty CNC words; 2. a set of sixty monosyllabic words containing initial and final consonant clusters; 3. a set of fifty spondees; and 4. a set of forty brief sentences. The lists were recorded by the speakers in the recording room at the Communication

DYSARTHRIC SUBJECTS

Subject Number	Age	Educational Level	Occupation	Neurological Diagnosis	Etiology	Date of Onset	Qualitative Judgment of Severity	Amount of Speech Therapy
1	42	M. D.	M. D.	Posttraumatic Brain and Cerebellar Deficit	Auto Accident	6/19/58	Moderate	2 mos.
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4	38	College (3 yrs.)	Sales Engineer	Closed Head Injury	Auto Accident	7/59	Mild-Moderate	2 wks.
5	35	10th grade	Factory-Laborer	Postencephalitic	Acute Encephalitis	1/60	Severe	None
6	20	College (2 yrs.)	Student	Posttraumatic Encephalopathy	Auto Accident	8/2/58	Moderate-Severe	3 yrs.
7	47	12th grade	Oiler	Unilateral Parkinsons	Encephalitis (?)	1936	Severe	None
8	38	High School	Unemployed	Fredric's Ataxia	Unknown	1929	Moderate	None
9	25	College (2 1/2 yrs.)	In service at time of accident	Posttraumatic Brain Stem Damage	Auto Accident	12/20/57	Moderate	1 1/2 yrs.
10	52	B. A.	President of own Corporation	C. V. A.	C. V. A.	4/22/58	Severe	3 yrs.

Slide 1

Sciences Laboratory or in the Neurology Research Laboratory at The University of Michigan Medical Center.

A set of three listening tapes containing the three word lists was constructed for each of the dysarthric speakers, and one for the normal speaker. The sequence of word lists appeared in a different order on each of the listening tapes. The tapes were played to listeners through a single TDH-39 earphone. Each listener was required to write the word that he thought the dysarthric uttered. No clues were present to aid the listener. Then listeners were used for each listening tape for each dysarthric subject, so that a total of 30 listeners responded to each speaker. Only one tape was used for the normal speaker with ten listeners. A total of 49,600 responses form the basis of the intelligibility data. The listeners were students at The University of Michigan and members of the Communication Sciences Laboratory staff who were not participants in this research.

Intelligibility was measured in terms of the number of words correctly indentified by a normal listener. The present paper is not concerned with an individual word analysis but rather with overall intelligibility. The following scores were computed from the listener responses:

1. A total intelligibility score. This score represents the total number of correct responses made by all of the listeners for a particular dysarthric subject.

2. A total order intelligibility score. This score represents the total number of correct responses made by all of the listeners for a particular dysarthric subject for a given order. Thus there are three total order intelligibility scores.

3. A total list intelligibility score. This score represents the total number of correct responses made by all of the listeners for a particular dysarthric subject for a given list without regard to order.

4. A total list by order intelligibility score. This score represents the total number of correct responses made by all of the listeners for a particular dysarthric subject for a given list in a given order.

Two approaches were employed in the analysis of these data. An analysis of variance was performed to evaluate differences between dysarthric speakers, lists and orders and their respective interactions. In addition, the subjects were rank-ordered according to their intelligibility scores.

The scores made by the listeners for nine of the ten dysarthric subjects were used in the analysis of variance. The scores for subject 8 were so low and demonstrated so little variability that they would have exerted an undue influence on the analysis. In fact, the total number of correct responses made by all of the listeners was 21 out of a possible 4800. Slide 2 presents the summary of the

Summary of analysis of variance to evaluate differences between dysarthric speakers, lists, and orders

Source	df	ms	F
Subjects (A)	8	12293.6	105.1*
Lists (B)	2	583.7	1.4
Orders (C)	2	85.5	2.6
AB	16	404.4	34.6*
AC	16	32.2	2.8*
BC	4	2599.4	10.9*
ABC	32	239.2	20.4*
within Cells	729	11.7	
Total	809		

*Significant

Slide 2

analysis of variance. As can be seen from the slide there was only one significant main effect, that for subjects. None of the other main effects were significant. This is interpreted as indicating that for the population of dysarthrics taken as a whole neither the list used nor the order of presentation of the lists was important. All of the interactions, however, were significant at the .01 level of confidence. This finding is interpreted as indicating that for a given dysarthric the listeners' ability to identify the stimulus correctly is a function of the list and the order in which it was presented. In addition, the significant lists-order interaction indicates that listeners' performance will vary with respect to list and order in the sequence with regard to the particular speaker. The least significant interaction was between subjects and order. It is felt that order plays a lesser role in producing variation in listener performance than either the subject list or the combined speaker list order effects. It may be concluded from these findings that if one is interested only in population data, list and order may be ignored. However, if information about a particular speaker is desired, then a variety of lists must be employed and the sequence in which the lists are presented to listeners must also be varied.

The dysarthric subjects were rank-ordered on the basis of listener responses in four ways: 1. by lists without regard to position; 2. according to position on the listening tapes; 3. by list and position on the listening tape; and 4. total intelligibility. The scores for all ten subjects were used in this analysis. In addition, the scores made by the listeners on the second recording of subject 9 were also included.

Slide 3 shows the rank order of the dysarthric subjects based on the order of presentation of lists, list type and total intelligibility score. The subjects identified by numbers are ranked in each column in descending order according to the number of correct listener responses. The first section of this slide shows the rank order of the subjects by list and position on the listening tapes. Subjects 4, 10, 5, and 2 are always ranked in the same position with respect to the other subjects. This occurs for all lists with respect to the other subjects. Some of the subjects, however, do show shifts in rank order by as much as three positions. These shifts occur more frequently for the CNC lists than for either clusters or spondees. When the intelligibility scores are collapsed over order, as shown in the second section of this slide, the rank order of the subjects remains stable except for subjects 9a and 7. The third section of the slide presents

Rank order of dysarthric subjects based on the order of presentation of lists, list type and total intelligibility scores.

Rank Order by List and Position on Listening Tape										Rank Order by List without regard for Position on Listening Tape			Rank Order in terms of Total Score
CNC					CL					SP			
1	2	3	1	2	3	1	2	3	CNC	CL	SP		
4	4	4	4	4	4	4	4	4	4	4	4	4	
1	6	6	8	6	6	1	6	6	6	6	6	6	
6	9a	1	6	8	8	6	1	1	1	1	1	1	
8	1	7	1	1	1	7	7	7	8	8	8	8	
9a	7	3	9a	9a	7	9a	9a	9a	9a	7	7	7	
3	8	8	7	7	9a	8	8	9b	7	9a	9a	9a	
7	3	9a	9b	9b	9b	3	3	3	3	3	3	3	
9b	9b	9b	3	3	3	9b	9b	8	9b	9b	9b	9b	
10	10	10	10	10	10	10	10	10	10	10	10	10	
5	5	5	5	5	5	5	5	5	5	5	5	5	
2	2	2	2	2	2	2	2	2	2	2	2	2	

the rank order for the total intelligibility scores. It can be observed that the rank order for the subjects here is the same as that for the total list scores with the exception of subjects 9a and 7. The information offered by rank ordering supports the results on the analysis of variance.

An additional rank order analysis was performed according to the position of the lists on the listening tape. This analysis is shown in slide 4. Examination of these data reveals that the greatest stability of rank order occurs in position one. Six of the subjects do not shift rank order between lists when they occur in the same position on the listening tapes. However, when shifts in rank order do take place, they tend to be of greater magnitude in this analysis than at any other point. Shifting of rank order also occurs with greater frequency in this analysis than it does with respect to the criteria described in Slide 3. These findings confirm the observation. In order to evaluate fully the speech of the dysarthric with respect to intelligibility, it will be necessary to use several word lists and vary the order in which the lists are presented to listeners.

When compared to a normal speaker, the intelligibility scores of even the most intelligible dysarthric were significantly lower. Listeners did not get every word right for the normal speaker. However, only 34 misidentifications occurred in 1600 responses.

Rank order of subjects according to position
of the lists on the listening tapes

Position on Listening Tape									
Position 1			Position 2			Position 3			
List			List			List			
CNC	CL	SP	CNC	CL	SP	CNC	CL	SP	
4	4	4	4	4	4	4	4	4	4
1	8	1	6	6	6	6	6	6	6
6	6	6	9a	8	1	1	8	1	1
8	1	7	1	1	7	7	1	8	8
9a	9a	9a	7	9a	9a	3	7	7	7
3	7	8	8	7	8	8	9a	9a	9a
7	9b	3	3	9b	3	9a	9b	3	3
9b	3	9b	9b	3	9b	9b	3	9b	9b
10	10	10	10	10	10	10	10	10	10
5	5	5	5	5	5	5	5	5	5
2	2	2	2	2	2	2	2	2	2

Based on the total number of correct responses, it appears that listeners have less difficulty with spondees than either clusters or CNC's. Obviously, spondee words contain contextual information which is not present on the other two lists. The most difficult list was the cluster list. This was true for the normal as well as for the dysarthric speakers.

Although it would be of great interest to relate the intelligibility data to the acoustic-phonetic findings, it does not seem feasible when the analysis is limited to overall scores. It is necessary that further analysis of intelligibility be carried out with respect to the individual words before a clear relation to the acoustic data may be established. However, such overall scores permit the development of techniques by which scales of dysarthric impairment with respect to intelligibility may be developed.

Appendix VII

Intelligibility of Dysarthric Speech

Intelligibility of Dysarthric Speech

presented at

Meetings of the American Speech and Hearing Association

November, 1963

R. P. Tikofsky

T. Glatcke

G.L. Reynolds

The dysarthrias present a wide range of interesting and challenging problems for the speech pathologist and neurologist. For the purposes of the research reported in this paper, we shall define dysarthria as a disorder of articulation and/or phonation due to a lesion in those parts of the nervous system which control and regulate the articulatory and phonatory mechanism. Such lesions result in distortions, substitutions and omissions of the phonetic elements of the speech signal, as alternations in rhythm, rate and vocal quality.

One parameter of dysarthric speech which is of great interest to the speech pathologist is intelligibility. If one of the aims of treatment is to increase the patient's intelligibility, then an objective measure of intelligibility would provide the therapist with a somewhat more accurate means for determining progress in treatment. Such measures, coupled with data obtained from acoustic-phonetic analyses of dysarthric speech, might also

result in more precise systems of classification.

The primary aim of this research was to compare the intelligibility of dyarthric and normal speakers, based on listener responses to tape recorded utterances. Listener responses were analyzed to determine whether there were differences in the overall intelligibility among three lists of recorded words. In addition, we were interested in the effects of changing the order in which the lists were heard by the listeners. Comparisons of the intelligibility scores for each subject on each list were made to determine if his relative position across the lists remained constant.

Listener responses were scored so as to yield overall scores for each list as well as compiled scores for each word. The data present in this paper are based on the list scores.

Three word lists were recorded by each of the speakers: fifty CNC words; sixty monosyllabic words containing initial and final clusters; and fifty randomly selected spondee words were used. In all, each speaker recorded one hundred and sixty words.

The recordings were made in the recording studio of the Communication Sciences Laboratory in a sound treated room at The University of Michigan Medical Center. The recording environment of the two rooms was

approximately equal, and the recording equipment was equivalent in both situations. Only two of the speakers were recorded at the Medical Center. Each speaker was instructed to repeat the word spoken by the experimenter. None of the speakers demonstrated a hearing loss as determined by audiometric screening examination. As far as could be determined from the neurological and speech examination, none of the speakers had any perceptive impairment.

A set of three listening tapes containing each of the word lists was prepared from the master tape made by each speaker. Each list appeared in the first, second, or third position on a given listening tape. No list appeared in the same position on any two tapes. The instructions to the listeners were also recorded on the tapes. However, the experimenter's instructions to the speakers did not appear on the listening tapes.

The tapes were played to the listeners through a single TDH-39 earphone at a comfortable intensity level. Each listener had his own headset, and one of the phones was a dummy. In most cases, we had five listeners responding in a listening session. The listeners were required to write the word they heard; if they could not understand a word they were told to draw a line in the space for the word on the response forms.

Intelligibility was measured in terms of the number of words correctly identified by the listeners. Four separate

intelligibility scores were computed: a) total intelligibility, the total number of correct responses made by all of the listeners for a given speaker over all of the lists; b) total order intelligibility, the total number of correct responses made by all the listeners for a speaker for each order, that is, listening tape; c) list intelligibility, the total number of correct responses made by all of the listeners for a speaker for a list, without regard to the position of the list on the listening tapes; and d) list by order intelligibility, the total number of correct responses made by all of the listeners for a speaker on a list in a given order on the listening tape.

The dysarthric population was composed of ten males ranging in age from 20 to 65 years. The educational as well as occupational background of these subjects varied considerably. Post-traumatic brain damage produced the cerebral insult which resulted in the dysarthria in four cases. Localization of the lesion in all ten cases was gross when it could be established. Three of the patients had received extensive speech therapy. Ten normal speakers approximated the dysarthric population in terms of age, education, and occupational status. Although an attempt was made to achieve a precise pairing between dysarthrics and normals, this was not always accomplished. Therefore, the matches between individual subjects was sometimes gross,

particularly with respect to education and occupational status. On the whole, however, there was a fairly even match between groups.

All of the speakers were native to the middle west or came to the area before they might have developed the dialect pattern of their place of birth.

Ten listeners responded to each of the listening tapes, making a total of thirty listeners for each speaker. None of the listeners had a history of a hearing loss. The hundred listeners who participated in this study were students in speech courses at The University of Michigan.

A summary of the mean number of correct responses to each speaker for each list (without regard to order) and across all lists is given in Table 1. A maximum score for a single listener on the CNC's and Spondees is fifty, and for the Clusters, sixty.

One dysarthric subject's intelligibility scores were not included in the analysis. His scores were so low, that it was felt that he was more characteristic of a true anarthria, rather than dysarthria. In all, there were only 21 correct responses out of a possible 4800 responses for this subject. Because the matches between groups was gross, and the fact that separate analyses were carried out, this subject's match was included in the analysis of the normal subjects.

Examination of the data reveals a marked difference between the dysarthrics and normals. The two populations are clearly different from each other. In only one instance was there any overlap in scores, and some of this overlap may be accounted for by the fact that the two subjects were not a matched pair. The dysarthrics come closest to the normal on the spondees, with a mean of 47.2 correct responses across subjects, as against a mean of 49.5 for the normals. Although the difference between means for the two groups is only 12.3, the range in individual means for the dysarthrics was much greater than that for the normals. The lowest mean for the dysarthrics is 16.8 and the highest 47.6, a range of 30.8, while the lowest mean for the normals is 49.2 and the highest 49.8, a range of only .6. In the case of the CNC's and Clusters the differences between the two groups is more obvious. However, the most significant information to be derived from this data is not in the absolute differences, but rather in the distribution of scores within each group. It is obvious from these data that, although there are differences between the normals, these differences, on the whole, are slight. The distribution of scores among these subjects is not very great. On the other hand, there is a much greater difference between the dysarthrics. Several other analyses

were carried out to examine the differences between the dysarthric speakers.

Kendall's coefficient of concordance was employed to compare the subjects' rankings on the three word lists and on the total test intelligibility score for the three orders of presentation. Comparisons were also made across the three lists, and across the lists plus the total test score without regard to order of presentation. The obtained coefficients are all significant. This suggests that it should be possible to predict a given dysarthric's rank on one of the word lists from his total intelligibility score, or from one of the other lists.

An analysis of variance was carried out to determine whether there are significant differences between subjects, lists, and orders, as well as the interactions between subjects and lists, and between order and lists. In order to account for the difference in maximum score between the Cluster list and the other two lists, the raw scores were converted to standard scores. A separate score was derived for each list.

The only values of F significant beyond the five per cent level were for subjects and for all of the interactions. These findings suggest that there are significant differences between subjects. However, when the group is taken as a whole, the order in which the lists are presented and, for that matter,

which of the three lists is used, has little effect on the obtained intelligibility scores. Although all of the interactions are significant, the ones which are the most interesting are the subject by list and subject by order. In the case of the former, the significant interaction suggests some subjects may have more difficulty in producing intelligible speech on one list than they might have on another. This difference may be related to the nature of the articulatory act required to produce the words on a particular list. That is to say, a particular subject's dysarthric impairment may make it more difficult for him to produce one set of words as against another. In like fashion, the significant subject by order interaction suggests that the listeners may derive some benefit from having heard some of the words before others. This goes along with significant list by order interaction.

The results indicate that there is a great difference between the intelligibility of dysarthric and normal speakers, as measured in this research. This wide separation does not allow us to consider the dysarthric's impaired intelligibility as an extension of the low end of the distribution of normal speakers on these measures of intelligibility. Thus it seems more fruitful to study the two populations independently.

There appears to be no direct relation of the degree of impaired intelligibility based on a subject's rank and the nature of the etiology of the lesion. Nor does there seem to be a direct relation between age, time since onset, level of education, and gross localization, to the degree of intelli-

gibility impairment. There is only fair agreement between the subjective judgement of a speech pathologist as to the severity of the dysarthria and the subject's rank and intelligibility, as determined in this study.

Although it cannot be obtained directly from the data, it is our impression that the resultant decrement in intelligibility seen in the dysarthric is most likely a function of the speaker's previous level of intelligibility and the locus and extent of the lesion.

Our findings do, however, indicate that it is possible to differentiate between dysarthrics in terms of intelligibility, as measured in this research. It is our impression that many of the words contained in the three lists contribute little to making this estimate. A more detailed examination of the words contained in the lists is necessary. This will lead to a reduction of the length of the lists, and possibly, to one list which contains those words which best discriminate between dysarthrics. It does seem reasonable to conclude from our results that the variability seen in our dysarthrics is characteristic of the dysarthric population as a whole. We also feel that it is possible to develop objective measures of some aspects of dysarthric intelligibility based on listener judgements. If such objectivity could be achieved, we could avoid the use of such terms as "mild," or "moderate" in the evaluation of the dysarthric impairment.

We are quick to agree that measures of intelligibility based on single words probably do not offer the best estimate of overall intelligibility, but they do provide a starting point for further research.

Table 1. Mean number of correct responses by listeners to nine dysarthric and ten normal speakers, on the CNC, Cluster, and Spondee word lists, and for all lists combined for each speaker, and for all speakers.

Subject	CNC*	Cl**	Sp	Mean for all lists***
D-1	40.5	49.5	37.6	137.6
D-2	35.3	45.1	47.3	127.7
D-3	34.7	41.5	46.9	123.1
D-4	29.9	44.5	36.0	110.4
D-5	32.0	29.2	42.5	103.7
D-6	28.1	32.7	41.4	101.9
D-7	28.9	17.9	37.5	84.2
D-8	21.3	10.7	19.7	51.2
D-9	10.2	6.9	16.8	33.9
Mean for all speakers	28.9	30.8	37.2	97.1

Table 1. (cont.)

Subject	CNC*	C1**	Sp	Mean for all lists***
N-1	47.7	58.5	49.8	156.0
N-2	47.7	58.6	49.5	156.2
N-3	49.1	58.9	49.5	157.7
N-4	47.2	56.4	49.8	153.5
N-5	48.8	59.3	49.5	157.6
N-6	48.4	57.5	49.5	155.4
N-7	42.8	55.7	49.2	147.7
N-8	49.0	59.0	49.6	157.7
N-9	42.1	48.7	49.2	140.2
N-10	48.2	58.5	49.8	156.5
Mean for all speakers	47.1	57.1	49.5	153.8

*Maximum number correct = 50

**Maximum number correct= 60

***Maximum number correct=160

Intelligibility of Dysarthric Speech

Table 2 - Kendall coefficients for CNC, Cl, Sp, and Total intelligibility scores across three orders of presentation for dysarthrics.

List	W	P
Dysarthrics		
CNC	.926	.010
Cl	.993	.005
Sp	.970	.005
Total	.993	.005

Table 3 - Kendall coefficients across the CNC, Cl, and Sp lists, and across the CNC, Cl, Sp, and Total lists for dysarthrics.

Lists	W	P
Dysarthrics		
With Totals	.960	.005
Without Totals	.955	.005

Intelligibility of Dysarthric Speech

Table 4 - Summary of analysis of variance for the standard intelligibility scores of the dysarthric population, N=9

Source	df	ms	F	P
Subjects (Sub)	8	7307.57	953.99	.001
Lists (Lst)	2	788.71	2.68	NS
Orders (Ord)	2	70.00	2.36	NS
SubLst	16	294.66	38.47	.001
SubOrd	16	29.64	3.87	.001
LstOrd	4	86.19	5.40	.005
SubLstOrd	32	15.95	2.08	.005
Within	729	7.66		
Total	809			

Appendix VIII

Listener Confusions of Dysarthric Speech

Listener Confusions of Dysarthric Speech

Theodore J. Glattko

Paper presented at the American Speech and
Hearing Association, November, 1963

The previous paper reported wide individual differences among dysarthric speakers in terms of word intelligibility. We also demonstrated that there was essentially no overlap between the dysarthrics and normals on our intelligibility measures. In spite of the fact that the mean number of correct responses made to normal speakers was quite high, listeners did make errors. However, our initial study made no attempt to examine the nature of the perceptual confusions made by listeners to normal or dysarthric speech. In view of the results reported in the first paper, we felt that such an analysis might reveal important clues regarding the nature of dysarthric speech, as well as point to important differences between dysarthrics. The results of such analyses might be correlated with the type, locus, extent of lesion, and time since onset of the dysarthria. Further, comparisons of the perceptual errors made by the listeners in response to normal and dysarthric speech might be of significance to the speech pathologist who is attempting to treat the dysarthria.

It has been well established that the perception of the normal speech signal may be interfered with by altering the signal before it reaches the listener's ear.

A variety of techniques to accomplish this interference or distortion have been reported in the literature. Another technique used to study speech intelligibility has employed synthesized speech. In these experiments the listener attempts to identify the signal when one or more of the parameters of the signal have been manipulated in the production of the synthetic speech. However, these techniques employ "artificial" means to distort the speech signal. In this sense they do not permit any conclusions to be drawn regarding the amount and type of distortion produced by impaired articulation and phonation.

Lesion in the nervous system which interferes with the control of the articulatory and phonatory mechanism produces distorted speech signals. This is roughly analogous to the experimental situation in which "noise," in its broadest sense, is superimposed on an otherwise normal speech signal. The major difference here, of course, has to do with the experimenter's ability to control the "noise," and the degree to which the parameters of the speech signal can be manipulated. Little control or manipulation of the signal can be achieved when one considers the dysarthric speaker as a generator of distorted speech signals. We recognize, of course, that it is possible to introduce some control by speech therapy, but our argument still holds for the hypothetical case. Therefore, the analysis of the errors made by listeners to speech signals produced by dysarthrics might tell us something about the nature of the noise.

The purpose of the present paper is to present a preliminary description of the type and frequency of the consonant errors made by listeners responding to dysarthric and normal speech. Particular emphasis is placed on the analysis of consonant confusions. In addition to a descriptive analysis of the consonant errors, we were also interested in seeing if there were differences between the proportion of confusions made for initial and final consonants, if the pattern of listener confusions for initial and final consonants differed, and whether the patterns of listener confusions varied from speaker to speaker for either the initial or final consonants.

The details of the experimental method were given in the preceding paper. To review briefly, we recorded ten male dysarthrics and matched ten normal speakers to them. Each speaker recorded three lists of words, fifty CNC's, sixty Clusters, and fifty Spondees. Thirty normal hearing listeners responded to each speaker by writing the word they thought they heard the speaker say. Only responses to the CNC words were analyzed for this study. The CNC words used in this research contained twenty initial and twenty final consonants. The initial and final consonants were the same in sixteen instances. Some of the consonants appeared only once in the list, while some occurred as many as six times. Each time a consonant appeared it was responded to by thirty listeners for each speaker.

The listeners' written responses to the fifty CNC words were scored as incorrect if any portion of a word

deviated from what was intended by the speaker. However, a listener response was scored as correct if the word could be pronounced in the manner intended by the speaker. Only consonantal errors were evaluated in this research.

All of the errors made by the listeners were tabulated independently for initial and final consonants. The tabulations were performed by an IBM 7090 computer. A program was developed to analyze the total number of errors for each set of ten listeners for each order of presentation and across all thirty listeners for each speaker. These results were then combined for all speakers and listeners for the initial and final consonants. In addition to these tabulations, the computer output produced confusion matrices which indicated the nature of the error made by the listeners. That is, the confusion matrices summarized the consonants which the listeners substituted for the one intended by the speaker. In this way, it was possible for us to determine how frequently a particular consonantal confusion occurred for a given speaker, as well as the total number of each consonantal confusion summed across all speakers.

One of the dysarthrics was almost totally unintelligible, and he and his control were excluded from the analysis.

Table One of the handout gives the number of possible responses to each of twenty-four consonants which occurred in the CNC word list. In addition, the table also presents the per cent correct responses by listeners to the dysarthric and normal speakers. The range in per cent of correct responses

to initial consonants for the dysarthrics is 92.9 for the /s/ to a low of .8 for /j/. For normal speakers the range is 99.8 for /l/ to a low of 77.1 for /v/. It is interesting to note that no errors were made for seven of the nine normal speakers on the /v/. One error was recorded for one speaker, 24 and 30 for two others. In fact, three normal speakers contributed 178 of the 230 listener confusions made by the listeners for initial consonants. For final consonants, the range in per cent correct responses for dysarthrics is 86.4 for the /l/ and a low of 41.0 for the /g/. Perfect recognition of final consonants for all normal speakers occurred on the /f/, /ʃ/, and /tʃ/. The low was 88.3 per cent for /b/. Of the 366 confusions made by listeners, two speakers contributed 110 and 127 errors.

Examination of the raw data for each dysarthric speaker on each consonant did not indicate any clear-cut patterns which would permit distinctions between speakers to be made with any degree of confidence. However, it did appear that certain classes of consonants, when produced by dysarthric speakers, evoked listener confusions in speakers whose overall intelligibility was high for the dysarthric group. This finding must be interpreted broadly. The pattern does not always hold up. There appears to be a unique combination of overall intelligibility and difficulty in the articulation of some consonants for each dysarthric.

Kendall's Coefficients of Concordance were computed to examine the stability of rank between initial and final consonants for the dysarthrics. A coefficient of .69 was obtained. This suggests that, on the whole, the same consonants were as difficult for the listeners to perceive in the initial and final positions. The most notable exceptions

Kendall's Coefficients of Concordance were computed to examine the stability of rank between initial and final consonants for the dysarthrics. A coefficient of .69 was obtained. This suggests that, on the whole, the same consonants were as difficult for the listeners to perceive in the initial and final positions. The most notable exceptions to this were /v/, /dʒ/, /g/, /tʃ/, and /p/.

The single most intelligible consonant in the initial position for the dysarthrics was the /s/, while the nasal /m/ and the sonorants /r/ and /l/ were the most intelligible final consonants for the dysarthrics. This may, in part, be accounted for by the context in which the consonant was presented. The linguistic constraints may have been such that the listeners could predict what the sound, or, rather the word could be only on the basis of their knowledge of English. This suggests that, even if the sound is grossly distorted, it is correctly perceived because of these other factors. Spectrographic evidence tends to confirm these inferences.

When voiced and unvoiced consonants were compared, both normals and dysarthrics yielded higher intelligibility scores for the voiceless consonants. The mean intelligibility scores for the voiceless consonants were 98.1 and 75.6 per cent for normals and dysarthrics respectively, while for the voiced consonants the mean intelligibility scores were 95.3 and 68.5 per cent for normals and dysarthrics. Although these differences

are not great it may be concluded that listeners have somewhat more difficulty with voiced consonants than with unvoiced ones.

A comparison of the consonants, based on place of articulation, was also carried out. The grouping of the consonants and the results of the analysis are given in Table Two. There is essentially no difference in mean intelligibility scores as expressed in per cent correct responses for the normals. However, there is a slight trend in ease of identification, going from the "front" to "back" consonants. There; the reverse is true for the dysarthrics, except for the glottal /h/ which was most intelligible for both populations. The range in mean intelligibility for the dysarthrics is 45.0 to 80.1 per cent. Apparently, the distortion introduced by the dysarthria has a greater effect on the intelligibility of "back" consonants than on the "front" ones.

We also examined the intelligibility scores in terms of manner of articulation. Figure One is a plot of the per cent correct responses for normals and dysarthrics, when the consonants are grouped in this way. Again, there is virtually no difference between groups for the normal speakers. The range of difference in intelligibility scores for the dysarthrics shows little variation when the affricates are omitted. The range of scores were 70.6 to 79.6 per cent correct responses. However, only 55.7 per cent of the listener responses were correct for the affricates. This indicates that the dysarthric probably has more difficulty with sounds which require relatively complex articulatory acts. The two affricates do not require a static articu-

latory position but, rather, controlled movement to achieve the desired result. Even the most intelligible of our dysarthric speakers had trouble with the /dʒ/. This indicated that one of the major factors which impedes the accuracy of dysarthric intelligibility is a reduction in the control of graded synchronous movements.

An analysis of the errors made by the listeners was also performed. We found that omissions accounted for 30 to 60 per cent of the listener errors on both initial and final consonants for normal speakers. Twenty per cent of the errors made for the normals involved in the substitution of another consonant which differed from the one intended by only one distinctive feature. That is, a /d/ would be given by a listener when the speaker intended /t/. On the other hand, only about 5 to 12 per cent of the errors made in response to the dysarthrics were omissions. Thirty per cent of the errors were substitutions involving only one distinctive feature. The remaining errors were substitutions involving shifts of more than one distinctive feature.

The results of this study did not indicate any clearly distinctive patterns of errors made by listeners to the dysarthrics. There were, of course, marked individual differences between speakers. However, it was not possible to separate the speakers only on the basis of consonants they misarticulated. Those speakers whose overall intelligibility was high also had fewer consonantly misidentifications. However, careful examination of the individual differences do indicate that, on the average, some consonants are more

difficult for dysarthrics to articulate than others. These difficulties seem to be related to the dysarthric's ability to coordinate the articulatory and phonatory acts as coincidental behaviors. Spectrographic evidence supports such a contention. This seems also to be the case for those consonants which require dynamic, rather than static articulatory acts. It is perhaps interesting to note again, and attempt to explain why the most intelligible consonant for the dysarthrics should be /s/. We feel that listeners had less trouble responding to this sound for two reasons: One is that there may have been less alternatives to choose from as substitutes and, perhaps more important, because listeners tend to accept a fairly wide range of distortion of this consonant before making the substitution.

In view of the findings we have described, it seems that there may be some relation between the nature of the type of consonants misidentified by listeners and some aspects of the locus and extent of the lesion. However, we do not feel that intelligibility data as described here or the typical phonemic analysis are a good predictor of the extent or site of the lesion producing dysarthria. Before such predictions can be made we need to know much more about the neurologic control of the articulatory and phonatory mechanism.

We do believe that analysis, such as the one described in this paper, does provide beginning steps for further

research on the nature of the phonetic characteristics
of dysarthric speech

Table 1. Number of possible correct responses to 24 consonants in the CNC word list, and percent correct responses made by listeners to dysarthric and normal speakers.

Phoneme	Number of possible correct responses		Percent of Correct Responses			
	Initials	Finals	Initials		Finals	
			Dysarthric	Normal	Dysarthric	Normal
/p/	1080	810	74.0	98.3	84.0	95.6
/b/	810	270	69.9	94.4	63.3	88.4
/t/	810	1350	74.8	98.1	79.8	95.5
/d/	810	1080	67.5	97.5	75.3	99.1
/k/	810	1080	79.5	97.2	81.0	98.6
/g/	540	540	58.3	94.9	41.0	98.3
/m/	810	810	82.8	99.7	85.9	98.2
/n/	540	1620	86.4	99.3	78.5	98.1
/ŋ/	---	270	---	---	64.8	96.2
/f/	810	270	74.5	99.1	79.2	100.0
/v/	270	270	48.8	77.1	82.9	99.6
/s/	810	810	92.8	98.8	83.4	96.4
/ʃ/	540	270	74.4	99.3	75.5	100.0
/r/	1080	810	76.6	98.6	86.9	92.0
/l/	810	1350	72.9	99.8	86.4	91.7
/tʃ/	270	270	57.7	98.6	62.9	100.0
/dʒ/	540	270	58.5	99.7	44.0	92.5
/h/	810	---	80.1	99.2	---	---
/w/	810	---	82.9	98.2	---	---
/M/	270	---	72.9	86.7	---	---
/j/	270	---	44.8	96.0	---	---
/ə/	---	540	---	---	56.4	95.1
/z/	---	540	---	---	84.4	99.4
/ʒ/	---	270	---	---	47.7	92.2

Table 2. Mean intelligibility scores expressed in percent for consonants grouped by place of articulation made by listeners to dysarthric and normal speakers.

Consonants grouped according to place of articulation	Mean percent correct intelligibility	
	Dysarthrics	Normals
Bilabials	76.9	94.9
/m, b, p, ʙ/		
Alveolars	78.9	97.2
/n, d, t, s, z, l, r/		
Velars	64.9	97.0
/k, g, ŋ/		
Labio-dentals	71.3	93.9
/f, v/		
Inter-dental	56.4	95.1
/θ/		
Palatal	45.0	96.0
/j/		
Alveolar-palatal	60.1	97.4
/ʃ, ʒ, tʃ, dʒ/		
Glottal	80.1	99.2
/h/		

Table 3. Percent correct responses made by listeners to dysarthric and normal speakers when consonants are grouped by manner of articulation.

Consonants grouped by manner of articulation	Percent correct responses	
	Dysarthrics	Normals
Plosives /p, b, t, d, k, g/	70.7	96.3
Fricatives /v, f, θ, h, m/	70.6	93.8
Nasals /m, n, ŋ/	79.6	97.9
Sibilants /z, s, ʃ, ʒ/	76.3	98.9
Sonorants /r, l, w, j/	71.9	96.3
Affricates /dʒ, tʃ/	55.7	97.7

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