CHAPTER

26

A Comparison of Speech Kinematics among Apraxic, Conduction Aphasic, Ataxic Dysarthric, and Normal Geriatric Speakers

Malcolm R. McNeil
Scott Adams

Recent research examining the speech errors of apraxic speakers has employed a variety of instrumental measures, for example *acoustic* (Shankweiler, Harris, and Taylor, 1968; Kent and Rosenbek, 1983; Kent and McNeil, 1987; McNeil et al., 1989), *electromyographic* (Fromm et al., 1982), and *kinematic* (Itoh and Sasanuma, 1987; Robin, Bean, and Folkins, 1989; McNeil, Caligiuri, and Rosenbek, 1988), for a refined description of the disorder and for attribution of mechanisms for the errors. Each of these measures has provided data that tend to support a sensorimotor (phonetic) as opposed to a linguistic (phonologic) mechanism for apraxic speech. However, the great majority of data cannot be interpreted unequivocally.

Although the literature is abundant with quantitative movement studies of normal and dysarthric subjects (e.g., Abbs and Netsell, 1973; Hirose, 1986; Hirose, Kiritani, and Sawashima, 1982; Kuehn and Moll, 1976; Sussman, MacNeilage, and Hanson, 1973), relatively few studies (e.g., Fromm et al., 1982; Itoh and Sasanuma, 1984; Itoh et al., Ushijima, 1980) have evaluated labial, mandibular, lingual, and velar kinematics in apraxic speakers and even fewer (Itoh and Sasanuma, 1987) have examined speech kinematics in aphasic subjects. Even in the few kinematic studies of apraxic speech, data analysis has been largely descriptive of interstructural timing and coordination. Further, with the exception of the Itoh and Sasanuma (1987) investigation, studies have not examined intergroup differences relative to linguistic versus motor-control hypotheses. To our knowledge, only four studies (Itoh et al., 1980; Itoh and Sasanuma,1987; McNeil, Caligiuri, and Rosenbek, 1988; Robin, Bean, and Folkins, 1989) have compared qualitative data concerning the rate of movements in apraxic speakers with those of normal subjects in order to determine the actual movement velocity. Only Itoh and Sasanuma (1987) compared the kinematics of apraxic speakers with those of subjects with presumed linguistic (aphasic) disorders. No studies have compared the kinematic performance of apraxic subjects with the performance of subjects with known movement disorders (dysarthric subjects).

This investigation sought to determine if there were significant differences among apraxic, conduction aphasic, ataxic dysarthric, and normal groups in the kinematics of several movement-control parameters used in the coordinated production of speech. The experimental questions posed were: Are there significant differences among groups in (1) the duration of the continuous speech gesture, (2) the peak instantaneous velocity of the speech gesture, (3) the maximum displacement of the lip plus jaw, and (4) the time to peak velocity. In addition, the slope and correlation coefficients were computed from the peak velocity/displacement relation and compared across groups. The total utterance duration also was descriptively compared with the segment duration.

METHODS AND PROCEDURES

SUBJECTS

Seventeen adults served as subjects. One conduction aphasic (C3) subject's data was not used because he produced no on-target tokens for the utterance chosen for analysis. All were native English speakers and had speech discrimination of 70 percent or better at 40 dB HL in at least one ear. Five were normal controls without a history or evidence of speech, language, cognitive, or neurologic deficits. Those tests and each subject's performance on them most relevant to subject selection and description are summarized in Table 26-1.

Four subjects had apraxia of speech (AOS) without concomitant dysarthria or aphasia. Darley's (1982) definition was used for the conceptual determination of aphasia. Table 26-2 summarizes the selection criteria for all groups. Four conduction aphasic subjects were without accompanying dysarthria or apraxia of speech. Four ataxic dysarthric subjects were selected on the basis of the presence of ataxic dysarthria determined perceptually (Darley, Aronson, and Brown, 1975), a neurologic history and examination given at the time of data collection, and clinical or laboratory evidence consistent with a lesion or disease involving only the cerebellar system.

PROCEDURES

Data were collected with head-held movement transducers (Barlow, Cole, and Abbs, 1983) affixed to the upper lip, lower lip, and jaw. Movements during imitative speech were transduced in the midsagittal plane, and data were recorded on a 16-channel FM instrumentation recorder (Honeywell 5600 C) and later digitized on an IBM-AT computer (DT–2801AA/D board) at 1500 Hz and filtered at 750 Hz using Cspeech (Milenkovic, 1989). Data were analyzed with the same computer and *ASYSTANT+* data analysis program (Macmillan, 1986). Perceptually judged *on-target* productions (using broad phonetic transcription) of the measurement segment in the utterance "Buy Bobby a Poppy" were analyzed.

Data analysis involved displaying the analog movement for the lower lip plus jaw and concurrent acoustic signals for each trial. Cursors were placed at the onset and offset of the opening and closing gestures for the first /b/ in "Bobby" from the phrase "B*uy Bo*bby a Poppy" as well as at the first glottal pulse and the final glottal pulse of the acoustic waveform for the overall utterance duration (see Fig. 26-1 for the cursor place-

TABLE 26-1. SUMMARY OF BIOGRAPHICAL AND DESCRIPTIVE DATA FOR THE NORMAL CONTROL, SPEECH APRAXIC, CONDUCTION APHASIC, AND ATAXIC DYSARTHRIC SUBJECTS

	Subjects																
Measure	N1	N2	N3	N4	N5	A1	A2	A3	A4	C1	C2	C3	C4	D1	D2	D3	D4
Gender	M	M	M	M	M	M	M	M	M	M	M	M	M	F	M	M	F
Age	67	57	63	64	69	59	62	54	72	48	66	60	62	44	53	55	32
Time after onset (mos.)						62	64	39	48	60	02	04	62	—†	—†	—†	—†
S-F exam.	WNL	WNL	WNL	WNL	WNL	WNL*	WNL	WNL	WNL*	WNL	WNL	WNL‡	WNL‡	ABN§	ABN	ABN	ABN
Total RCPM	32	33	33	29	31	27	28	30	28	33	26	32	27	32	28	18	36
Total WFM	51	30	57	34	34	13	4	11	31	7	9	16	11	62	49	6	61
OA PICA	14.73	14.84	14.65	14.51	14.53	14.66	14.33	14.53	14.96	13.98	14.39	14.13	14.87	14.90	14.70	14.30	14.20
OA RTT	14.35	14.83	14.81	14.15	14.88	13.94	12.08	12.23	14.07	10.80	12.08	13.04	13.94	13.61	14.53	14.17	14.87
BDAE aud. comp.	119	117	112	117	117	116	113	118	116	110	115	117	114	117	117	113	119

BDAE speech ratings:																	
1. Artic. agility	7	7	7	7	7	2	4	3	1	6	5	5	5	1	4	3	2
2. Phrase length	7	7	7	7	7	7	4	4	4	7	5	5	5	7	7	7	7
3. Melodic line	7	7	7	7	7	3	4	4	2	7	5	7	5	4	7	6	2
BDAE total sent. rep. w/o errors	8	8	8	8	8	8	7	1	1	1	1	1	3	8	7	7	7
Apraxia bat. for adults:																	
1. Total limb	48	50	50	50	49	47	50	48	45	40	45	50	50	50	48	40	47
2. Total oral	50	50	49	50	49	43	37	49	43	48	49	49	49	49	50	49	49

*There was a questionable right-sided lingual weakness on clinical examination that was not confirmed with additional testing for this subject.
†The exact onset of the degenerative diseases causing the ataxic dysarthria was indeterminate.
‡There was a question of oral sensory diminution on clinical examination in this subject.
§Multiple oral sensorimotor abnormalities were exhibited by all dysarthric subjects.

TABLE 26-2. CRITERIA FOR SUBJECT SELECTION OF EACH OF THE FOUR SUBJECT (NORMAL CONTROL, APRAXIC, CONDUCTION APHASIC, ATAXIC DYSARTHRIC) GROUPS

Group	*Criteria*
Normal control:	
	1. Normal speech and language as determined by a battery of tests (see Table 26-1)
	2. Normal neurologic examination
Apraxic:	
	1. Presence of
	a. Effortful trial-and-error groping on the initiation of speech gestures
	b. Frequent single-feature sound substitutions
	c. Articulation and prosody as accurate on imitation as on spontaneous speech
	d. Variability of articulation and prosody on repeated trials of the same utterance
	e. BDAE ratings between 1 and 4 on articulation agility, phrase length, and melodic line
	2. Without evidence of
	a. Weakness or incoordination of the speech musculature when used for reflexive or automatic acts
	3. At or above the 1st percentile for normal subjects on the average of subtests II, III, V, VI, VII, VIII, X, and XI of the PICA
	4. A score of 22 or above on the RCPM
Conduction aphasia:	
	1. Without evidence of
	a. Apraxia of speech as defined above or dysarthria as defined below
	2. Presence of
	a. Frequent sound substitutions occuring more frequently in repetition than spontaneous speech
	b. BDAE speech ratings between 4 and 7 on articulation agility, phrase length, and melodic line
Ataxic dysarthria:	
	1. Same cognitive and linguistic inclusion criteria as the apraxic subjects defined above
	2. Neurologic history and examination consistent with a lesion or disease involving the cerebellar system
	3. Diagnosis of ataxic dysarthria using Darley, Aronson, and Brown (1969) perceptual criteria

ments relative to the movement trace and the acoustic signal). The movement signals were then digitally filtered (lowpass cutoff of 30 Hz) and differentiated. From these data, four measurements were made: (1) total duration of the closing and opening gesture (in milliseconds), (2) peak instantaneous velocity (in millimeters per second), (3) maximum

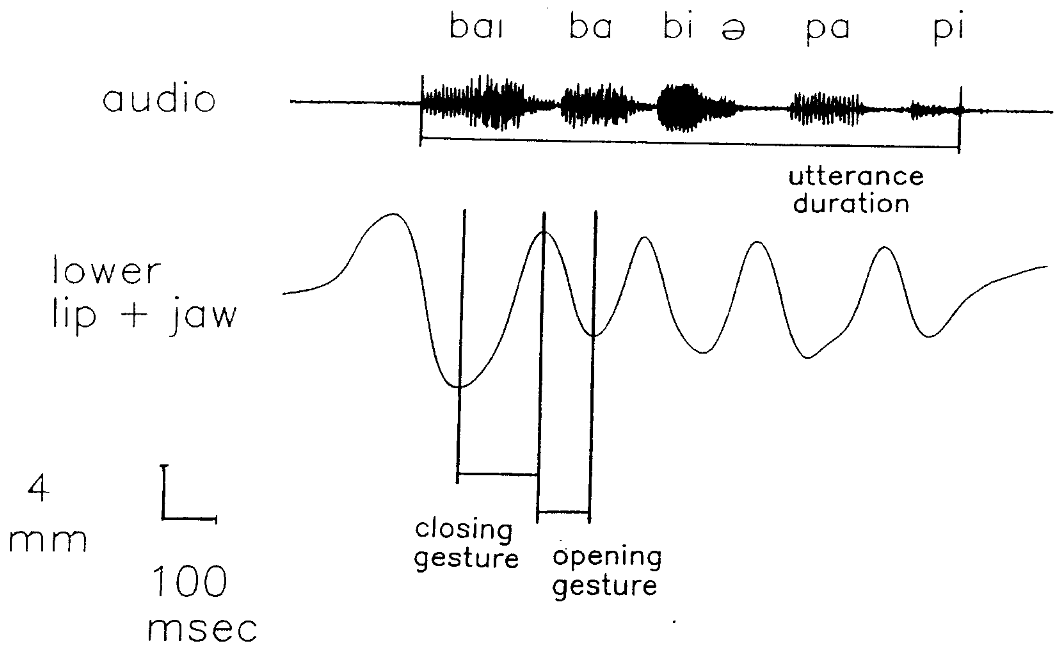

Fig. 26-1. The audio signal, lower lip plus jaw movement, and the segments measured for the utterance "Buy Bobby a Poppy."

displacement (in millimeters), (4) time to peak velocity (in milliseconds), and (5) total utterance duration (in milliseconds). The measurement of zero acceleration axis crossings was not included in this investigation as part of the replication of the McNeil, Caligiuri, and Rosenbek (1989) study. These data have been reported elsewhere (Adams, Weismer, and McNeil, 1989).

A series of planned pairwise comparisons (t-tests) were performed between each of the subject groups using the Dunn-Bonferoni procedure for adjusting the alpha level (alpha level of $.05/12 = p < .0042$). Each of the five kinematic measures was treated as a separate experiment in this study. The values for the five trials (when five *on-target* productions were available) of the utterance for all the subjects in each group were used for each of the analyses. Separate analyses were performed for the opening and closing phases of the lower lip plus jaw movements.

RESULTS

CLOSING GESTURES

Figure 26-2 provides a graphic display of the mean and standard deviations (error bars) for each group for each of the four kinematic measures

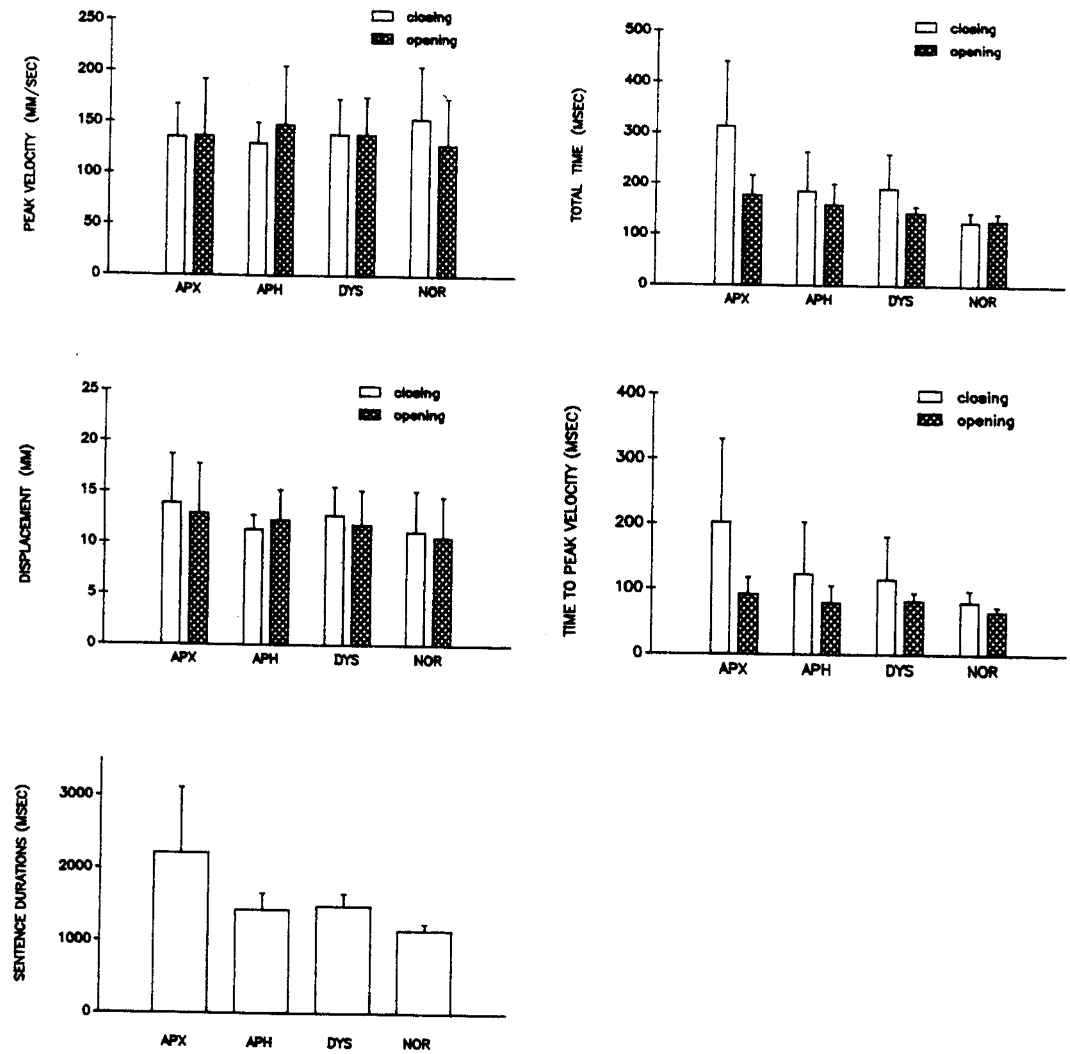

Fig. 26-2. Group data showing the mean and standard deviations for the four kinematic measures (peak velocity, total time, displacement, and time to peak velocity) and the single acoustic measure (sentence duration) obtained during the lower lip plus jaw opening and closing movements. *Note:* APX = apraxic, APH = conduction aphasic, DYS = ataxic dysarthric, NOR = normal.

for the closing (open bars) and opening (hatched bars) gestures and for the sentence duration. Table 26-3 presents a summary of the significant across group differences for each of the kinematic measures for both the opening and closing gestures. Velocity *(upper left column)* and maximum displacement *(middle left column)* were not statistically significantly different for any of the group comparisons. Intergroup differences were statistically significant for all comparisons for the time of the measured closing phase of this gesture *(upper right column)*, with the exception of the aphasic-dysarthric group comparison. The apraxic subjects produced significantly longer closing segment durations than all other

TABLE 26-3. RESULTS OF STATISTICAL COMPARISONS ACROSS GROUPS FOR THE OPENING AND CLOSING PHASES OF THE LOWER LIP PLUS JAW MOVEMENT

	Peak velocity		*Maximum displacement*		*Segment duration*		*Sentence duration*	*Time to peak velocity*	
	OPEN	CLOSE	OPEN	CLOSE	OPEN	CLOSE		OPEN	CLOSE
APX vs. APH						+	+		
APX vs. DYS					+	+	+		
APX vs. NOR					+	+	+	+	+
APH vs. DYS									
APH vs. NOR					+	+	+		
DYS vs. NOR					+	+	+	+	

Note: A (+) symbol indicates that the first group (APX = apraxic, APH = conduction aphasic, DYS = ataxic dysarthric, and NOR = normal subject groups) in the comparison had a significantly larger value than the second group for peak velocity, maximum displacement, segment duration, total sentence duration, and time to peak velocity.

groups, while the conduction aphasic and ataxic dysarthric subjects produced significantly longer durations than the normal subjects.

The total sentence duration *(lower left column)* was significantly different between groups for five of the six comparisons. The group differences for this total sentence-duration measure parallel those for the closing-segment durations. The only statistically significant difference between groups for the time to peak velocity occurred for the apraxic-normal group comparison, where the apraxic subjects produced a significantly longer average time to peak.

Although there were no significant across-group differences in peak velocity or displacement, there is, in normal subjects, a well-established relationship between these two measures. That is, in general, the greater the peak velocity, the greater is the displacement. It is possible, therefore, for pathologic subjects to achieve the same peak velocity or displacement as normal subjects, but to do so by varying either of the two parameters, but not both simultaneously. Therefore, we plotted the peak velocity against the displacement for each individual for the closing gesture only. Figure 26-3 displays these data for each of the four groups. The first column *(upper left)* displaying these data for the normal subjects shows the expected, rather narrow clustering of individual tokens for each subject along the computed regression line (slope = 12.6). Some subjects produced rather low peak velocities (e.g., N3) and displacements, while others (e.g., N5) produced considerably higher values. However, all subjects fall relatively close to the regression line. A correlation coefficient of +.98 (Pearson product moment) computed for these two variables supports the predicted relationship between peak velocity and displacement.

The second panel *(upper right)* illustrates the individual tokens for each of the apraxic subjects for the same peak velocity/displacement relationship. The smaller slope (5.09) and the smaller correlation coefficient (+.77) suggest a difference in the peak velocity/displacement relationship compared to normal subjects. However, only subject A1 demonstrates a substantive dispersion of velocity/displacement values along the regression line compared to normal subjects.

The third panel *(lower left)* summarizes the individual peak velocity/displacement data points for the conduction aphasic subjects. Although the computed slope (8.90) for the group is smaller than that for normal subjects but similar to that for dysarthric subjects, few individual tokens fell near the regression line. This extreme dispersion is verified by the low correlation coefficient (+.36). Furthermore, few trials within individuals fell close to the regression line, and individual subjects' peak velocity/displacement data points did not conform to the group's computed regression line. That is, when regression lines were computed for individual subjects, the direction of the line was opposite to that com-

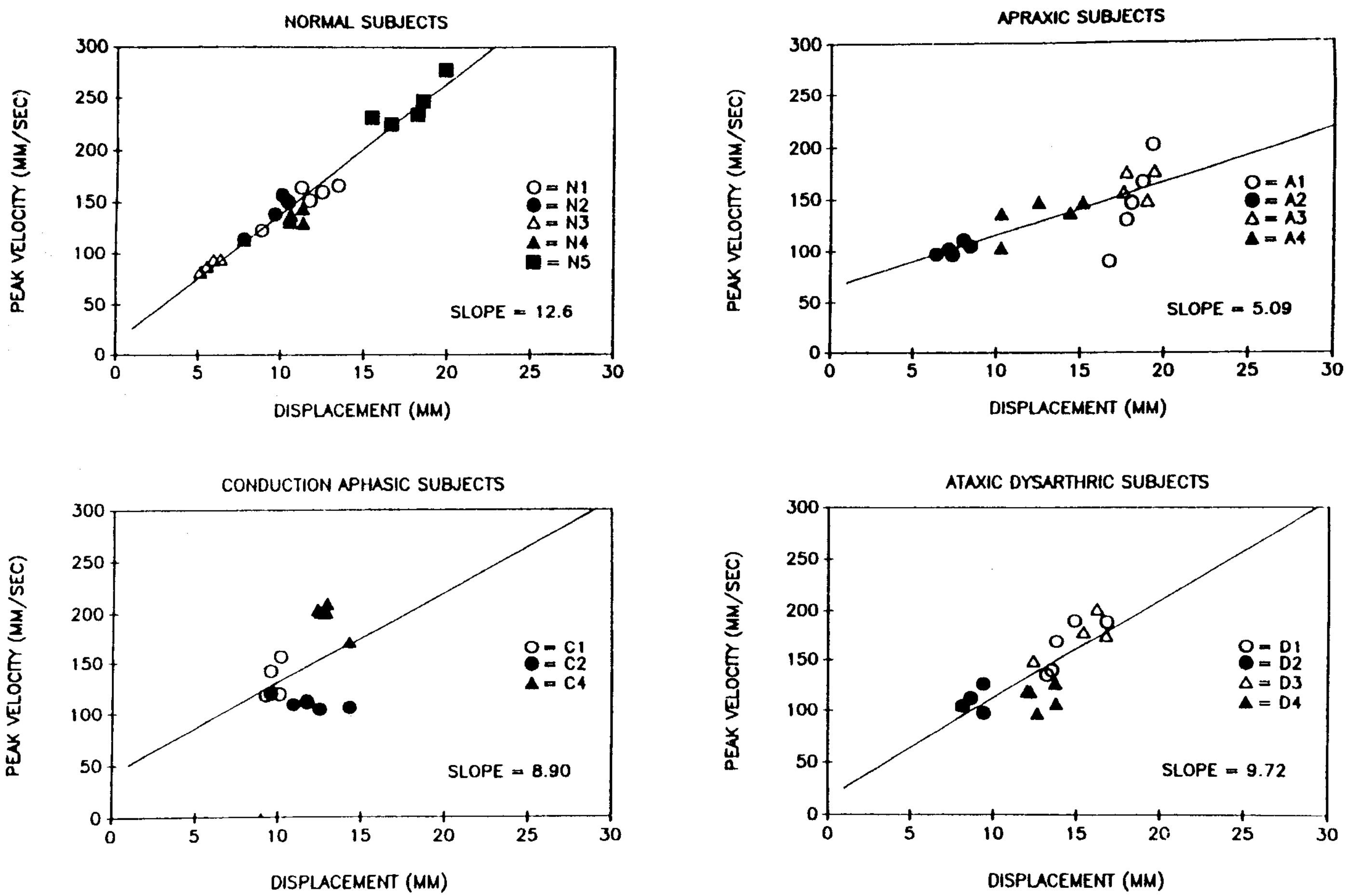

Fig. 26-3. Peak velocity versus displacement measures obtained for each individual in each subject group (by panel) for the closing gesture along with the regression line and its slope value.

puted for the group. The differences in dispersion and direction of slopes for individuals is greater for the aphasic subjects than for the other two pathologic groups.

The final panel *(lower right)* shows the peak velocity/displacement performance for the ataxic dysarthric subjects. This slope (9.72) is slightly lower than that for normal subjects, with more dispersion about the group regression line, especially for subject D4. This dispersion is confirmed by the correlation coefficient of +.79. Even with these differences, however, individual subjects' regression lines are similar to the group and reflect a peak velocity/displacement relationship similar in character to that for normal subjects.

OPENING GESTURE

As with the closing gesture, peak velocity and maximum displacement were not significantly different for any of the group comparisons (see Fig. 26-2 and Table 26-3). Intergroup segment duration comparisons followed those of the closing gesture except that the apraxic subjects were not significantly different from the aphasic subjects. The only significant between group comparisons in the time to peak velocity measure occurred for the apraxic-normal (as with the closing gesture) and dysarthric-normal comparisons, where these two pathologic groups produced significantly longer average time to peak than normal subjects.

DISCUSSION

The nonsignificant differences among groups for average peak velocity replicate those reported for apraxic speakers by Itoh and Sasanuma (1987), McNeil, Caligiuri, and Rosenbek (1988), and Robin, Bean, and Folkins (1989). The data from this study demonstrate that the apraxic, aphasic, and dysarthric subjects were capable of generating peak instantaneous velocities that were comparable to those of normal subjects. However, the extended segment and sentence durations of all pathologic groups relative to normal subjects suggests differences in the programming and execution of the gesture. Further, the differences in durations between the apraxic and the other two pathologic groups suggest additional motor-control deficits for the apraxic subjects.

The nonsignificant differences among groups for the maximum displacement do not confirm the McNeil, Caligiuri, and Rosenbek (1988) result for the same subjects on a different speech gesture. This finding is, however, consistent with the data extrapolated from the Robin, Bean, and Folkins (1989) and Itoh and Sasanuma (1987) studies. Despite the appearance of a restricted range of values for the pathologic subjects (especially the conduction aphasic subjects) relative to the normal subjects, it seems justified to conclude that the maximum displacement available to these subjects wasn't restricted or expanded.

The finding of significantly longer segmental durations in the apraxic subjects is consistent with the data reported by McNeil, Caligiuri, and Rosenbek (1988). This finding is also consistent with a substantial body of acoustic literature concluding that apraxic and dysarthric speakers take longer to produce speech gestures than normal subjects (Kent and McNeil, 1987; Kent and Rosenbek, 1982; McNeil et al., 1989). The finding that the conduction aphasic subjects produced significantly longer gestures than normal subjects but not significantly longer durations than dysarthric (both opening and closing gestures) or apraxic subjects (opening gesture) is counter to the prominent attribution of a linguistic mechanism to their speech-production errors. Further strengthening the interpretation of a motor component to the conduction aphasic subjects' speech is the fact that only phonetically on-target utterances were used in this analysis. That is, even when the utterance analyzed was judged perceptually to be "on target," the segment durations were not different from the apraxic or dysarthric productions but were significantly different from those of normal subjects. This finding is consistent with the findings reported by Kent and McNeil (1987) and McNeil et al., (1989) from an acoustic analysis of segment and intersegment durations in apraxic and conduction aphasic speakers. In order to explore this further, the total utterance duration was measured for each of the utterances from which the opening and closing gesture measurements were derived. An almost identical intergroup relationship was found for the total phrase duration as for the duration of the closing gesture. That is, the apraxic subjects' durations were significantly longer than those of the other three groups, while the aphasic and dysarthric groups produced significantly longer durations than the normal group for both the overall phrase *and* the segment durations. While this relationship does not provide a clear interpretation of the reason for this group's segment-to-whole-utterance duration similarity, it is interesting that the duration of the closing gesture for one phoneme in this multiphonemic utterance was consistent with the group performance for the overall phrase duration. One reasonable hypothesis to account for this is that the overall utterance duration is intimately related to the actual movement time rather than to the duration of pauses placed intersegmentally. This interpretation is, however, in need of experimental verification, since movement time, intersegmental time, or a combination of the two could account for this relationship.

The well-established regularity between peak velocity and displacement in neurologically normal persons, confirmed with the normal subjects in this study, was not as consistently found in any of the pathologic groups, especially the conduction aphasic subjects. The interpretation of this difference in motor-control terms is speculative. However, it appears that the conduction aphasic subjects not only utilized a restricted range of displacements (presumably the movement-control target), but also assigned the peak velocity in an aberrant manner. Cooke (1980) observed a similar reduction in the slope of the peak velocity/displacement relation in the arm movements of patients with cerebellar dysfunction. Referring to his "mass spring" model of motor control, Cooke suggested that this relation reflects a disruption in the control and regulation of muscular stiffness in cerebellar pathology. In terms of linguistic versus motor-control levels of explanation/interpretation, it is difficult to fit these kinematic differences into a linguistic model, even (or perhaps especially) in aphasic subjects. Given that there is some confidence that the subjects selected and produced the correct (the intended) phoneme, it is difficult to attribute aberrant control of velocity relative to amplitude to a phonemic selection level of production. At present, the best interpretation for the differences in all three pathologic groups is one placed squarely in the motor-programming and, perhaps, execution domains.

Taken as a whole, these data confirm other recent data on the kinematics of apraxic speech. Less is known about the kinematics of ataxic speech, and essentially nothing is known of the kinematics of conduction aphasic speech. It is difficult and unwise to use the data from a single instrumental study of speech production to propose changes in the theory or management of aphasic individuals' speech production. This is clearly not the intent of this discussion. In fact, the data reported do not address the segmental speech errors of the apraxic or conduction aphasic speaker. They do, however, provide support for the notion that speech motor-control deficits are apparent in the conduction aphasic (as well as the apraxic) that deserve additional research as well as the attention of clinicians charged with managing the speech of conduction aphasic and apraxic speakers.

ACKNOWLEDGMENTS

This research was supported by NINCDS Grant No. 18797 and NICHD Grant No. 5 P30 HD03352.

REFERENCES

Abbs, J. H., and Netsell, N. R. (1973). An interpretation of jaw acceleration during speech as a muscle forcing function. *Journal of Speech and Hearing Research, 16,* 421–425.

Adams, S. G., Weismer, G., and McNeil, M. R. (1989). Speech movement velocity profile analysis in neurogenic speech disorders. (In preparation).

Barlow, S. M., Cole, K., and Abbs, J. H. (1983). A new head-mounted lip-jaw movement transduction system for the study of motor speech disorders. *Journal of Speech and Hearing Research, 26,* 283–288.

Behrens, S. J. (1987). The role of the right hemisphere in the production of linguistic prosody: An acoustic investigation. In J. H. Ryalls (Ed.), *Phonetic approaches to speech production in aphasia and related disorders* (pp. 81–92). Austin, TX: PRO-ED.

Borkowski, J. G., Benton, A. L., and Spreen, O. (1967). Word fluency and brain damage. *Neuropsychologia, 5,* 135–140.

Cooke, J. D. (1980). The organization of simple, skilled movements. In G. E. Stelmach and J. Requin (Eds.), *Tutorials in motor behavior.* Amsterdam: North-Holland.

Dabul, B. (1979). *Apraxia battery for adults.* Austin, TX: PRO-ED.

Darley, F. L. (1982). *Aphasia.* Philadelphia: Saunders.

Darley, F. L., Aronson, A. E., and Brown, J. R. (1975). *Motor speech disorders.* Philadelphia: Saunders.

Fromm, D., Abbs, J. H., McNeil, M. R., and Rosenbek, J. C. (1982). Simultaneous perceptual-physiological method for studying apraxia of speech. In R. H. Brookshire (Ed.), *Clinical aphasiology,* Vol. 12 (pp. 251–262). Minneapolis, MN: BRK Publishers.

Goodglass, H., and Kaplan, E. (1983). *The assessment of aphasia and related disorders,* 2d Ed. Philadelphia: Lea & Febiger.

Hirose, H. (1986). Pathophysiology of motor speech disorders (dysarthria). *Folia Phoniatrica, 38,* 61–88.

Hirose, H., Kiritani, S., and Sawashima, M. (1982). Velocity of articulatory movements in normal and dysarthric subjects. *Folia Phoniatrica, 34,* 210–215.

Itoh, M., and Sasanuma, S. (1984). Articulatory movements in apraxia of speech. In J. C. Rosenbek, M. R. McNeil, and A. E. Aronson (Eds.), *Apraxia of speech: Physiology, acoustics, linguistics, management* (pp. 135–166). Austin, TX: PRO-ED.

Itoh, M., and Sasanuma, S. (1987). Articulatory velocities of aphasic patients. In J. H. Ryalls (Ed.), *Phonetic approaches to speech production in aphasia and related disorders* (pp. 137–162). Austin, TX: PRO-ED.

Itoh, M., Sasanuma, S., Hirose, H., Yoshioka, H., and Ushijima, T. (1980). Abnormal articulatory dynamics in a patient with apraxia of speech: X-ray microbeam observation. *Brain and Language, 11,* 66–75.

Kent, R. D., and McNeil, M. R. (1987). Relative timing of sentence repetition in apraxia of speech and conduction aphasia. In J. H. Ryalls (Ed.), *Phonetic approaches to speech production in aphasia and related disorders* (pp. 181–220). Austin, TX: PRO-ED.

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

Kuehn, D. P., and Moll, K. L. (1976). A cineradiographic study of VC and CV articulatory velocities. *Journal of Phonetics, 4,* 303–320.

Macmillan Software Company (1986). *ASYSTANT+*. New York: Macmillan Software Company.
McNeil, M. R., Caligiuri, M., and Rosenbek, J. C. (1988). A comparison of labiomandibular kinematic durations, displacement, velocities and dysmetrias in apraxic and normal adults. In T. E. Prescott (Ed.), *Clinical aphasiology*. Austin, TX: PRO-ED.
McNeil, M. R., Liss, J., Tseng, C.-H., and Kent, R. D. (1989). Effects of speech rate on the absolute and relative timing of apraxic and conduction aphasic sentence production. *Brain and Language* (in press).
McNeil, M. R., and Prescott, T. E. (1978). *Revised token test*. Austin, TX: PRO-ED.
Milenkovic, P. (1989). Paper presented to American Speech-Language-Hearing Association, St. Louis, Missouri.
Porch, B. E. (1967). *Porch index of communicative ability*. Palo Alto, CA: Consulting Psychologists Press.
Raven, J. C. (1962). *Coloured progressive matrices*. London: Lewis.
Robin, D. A., Bean, C., and Folkins, J. W. (1989). Lip movement in apraxia of speech. *Journal of Speech and Hearing Research, 32*, 512–523.
Shankweiler, D., Harris, K. S., and Taylor, M. L. (1968). Electromyographic studies of articulation in aphasia. *Archives of Physical Medicine and Rehabilitation, 1*, 1–8.
Sussman, H. M., MacNeilage, P. F., and Hanson, R. J. (1973). Labial and mandibular dynamics during the production of bilabial consonants: Preliminary observations. *Journal of Speech and Hearing Research, 16*, 397–420.