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24 Acoustic and Kinematic Correlates of Contrastive Stress Accent in Spoken English

Carol A. Fowler
Haskins Laboratories
University of Connecticut
Yale University

INTRODUCTION

Many studies have examined correlates of metrical prominence or "stress." A remarkable observation, evident across the studies, is that most variables that have been and imaginably could be examined show systematic change under stress variation. The following is a brief survey of acoustic and articulatory measures that have been found to index stress.

Acoustic Variables

As compared to unstressed vowels, stressed vowels are longer in their steady-state durations (e.g., Summers, 1987), and less centralized in their formant values (Harris, 1978; Summers, 1987; Tiffany, 1959). Formant transitions into and out of the steady-state are steeper for stressed than unstressed vowels (Summers, 1987). The stressed vowel's average fundamental frequency is generally found to be higher and to show more change (Lehiste, 1970; Lieberman, 1960; Summers, 1987; Tiffany, 1959) than the fundamental frequency of unstressed vowels. With effects of vowel quality controlled, stressed vowels are more intense than unstressed vowels (Lehiste, 1970). Finally, the slope of a "locus equation" relating F_2 at the midpoint of a vowel to F_2 at the transition onset of a stressed CV is shallower than the slope of the equation for an unstressed syllable (Krull, 1989), indexing a smaller coarticulatory influence of the stressed than the unstressed vowel on the preceding consonant; that is, the "coarticulation resistance" (Bladon & Al-Bamerni, 1976) of stressed segments is greater than that of unstressed segments.

Articulatory Variables

Measures of electromyographic activity for muscles implementing stressed consonants and vowels consistently show higher activity than for unstressed segments (Harris, 1978; Tuller, Kelso, & Harris, 1982). In addition, stressed syllables may be associated with increased activity of the internal intercostal muscles, which increase expiratory effort, as compared to unstressed syllables (Ladefoged, 1967).

As for kinématic measures, actions of articulators that implement gestures of stressed segments are generally longer in duration, show greater displacement and greater peak velocities than gestures for unstressed syllables (tongue dorsum for velar consonants and back vowels: Ostry, Keller, & Parush, 1983; jaw and lower lip for reiterant /ba/: Kelso, Vatikiotis-Bateson, Saltzman, & Kay, 1985; jaw for contrastively stressed CVCs: Summers, 1987). In Summers' research, in addition, low vowels were associated with lower positions of the jaw when stressed than when unstressed, and their "steady-state" positions were held longer.

All of these findings appear consistent with the proposal (Öhman, 1967; Lehiste, 1970) that stressing consists of a global increase in production effort. The globality of the increase in effort, if that is what it is, is underscored by the remarkable findings of Kelso, Tuller, and Harris (1983) that movements of the finger that accompany stressed syllable production are greater in amplitude than those accompanying unstressed syllable production, even though actors are instructed to keep movement amplitude constant.

New findings on stress are reported by investigators adopting a "dynamical systems" perspective on speech production. (See Turvey, 1990, for a discussion of the perspective itself applied to intentional action generally, and see Saltzman & Kelso, 1987, for a model. For applications to stress, see e.g., Ostry et al., 1983; Kelso et al., 1985; Vatikiotis-Bateson, 1987; Beckman & Edwards, 1992.) In general, speech gestures are modeled as varieties of oscillatory systems. In a simple mass spring system, the spring displacement over time, x, is equal to $A\cos\omega t$, where A is the maximum displacement of the spring during an oscillatory cycle, ω is angular velocity, and t is time. The velocity of the change in displacement is $\dot{x} = \omega A\sin\omega t$, where ωA is the peak velocity of the displacement change. A characteristic of this simple oscillatory system that is seen repeatedly in speech gestures (e.g., Kuehn & Moll, 1976) and other movements (e.g., Cooke, 1980) is a positive covariation between maximum displacement and peak velocity—that is, bigger displacements are associated with higher peak velocities. The slope of the line relating maximum displacement (A) to peak velocity (ωA) is ω.

Some investigators have found a difference in the slope of the displacement/peak velocity relationship for stressed and unstressed syllables, with unstressed syllables showing a steeper slope (Ostry et al., 1983; Kelso et al., 1985). That is, in unstressed gestures (associated, as summarized earlier, with smaller displacements and lower velocities than stressed gestures), greater changes in peak velocity accompany given changes in displacements than for stressed syllables. The slope of the line relating displacement to peak velocity is ω = (k/m)1/2, where k is spring stiffness and m is mass. Given that articulator masses do not change under variation in stress, the change in slope can be ascribed to changes in k or stiffness. From this perspective, the findings suggest that unstressed syllables are produced by a stiffer oscillatory system than stressed syllables.[1]

It is worth noting in this regard that not all investigators have found the slope difference between stressed and unstressed syllables. Vatikiotis-Bateson (1987) did find the difference in closing gestures (of reiterant /ma/ and /ba/ productions of the Rainbow passage), but he did not generally find it for opening gestures. Beckman and Edwards (1992) did not find a slope difference. They speculate that the reason for the difference between their findings and those of Ostry et al. and of Kelso et al. was that, whereas the latter investigators looked at lexical stress, they looked at accented and unaccented lexically stressed words. This account does not explain Vatikiotis-Bateson's inconsistent findings, however.

Beckman and Edwards (1992) proposed two other ways in which stressing might be achieved simply in a dynamical system. Stressed gestures may increase overall in amplitude relative to unstressed gestures, or sequential gestures may decrease in overlap. They contrasted the three hypotheses: a difference between stressed and unstressed gestures in stiffness, in amplitude or in phasing as shown in Figure 1 (following Beckman & Edwards, 1992).

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[1]Kelso et al. (1985) entertained, but rejected, a hypothesis that the stiffness difference they found between stressed and unstressed reiterant syllables was the product of a spring that was nonlinear such that net stiffness decreased with movement displacement. In such a system, stiffness would be greater for unstressed syllables not because talkers set stiffness to a higher value, but rather because unstressed gestures are smaller in magnitude than are stressed gestures. Making the assumption that each displacement midpoint approximated the equilibrium position of the oscillatory system responsible for the gesture, the investigators examined stiffness near the midpoint. If the data from stressed and unstressed gestures reflected a single nonlinear spring, then stiffness values near the equilibrium position should have been the same for stressed and unstressed gestures. Instead, they differed systematically. Accordingly, the investigators concluded that different stress levels were achieved using different settings of a stiffness parameter.

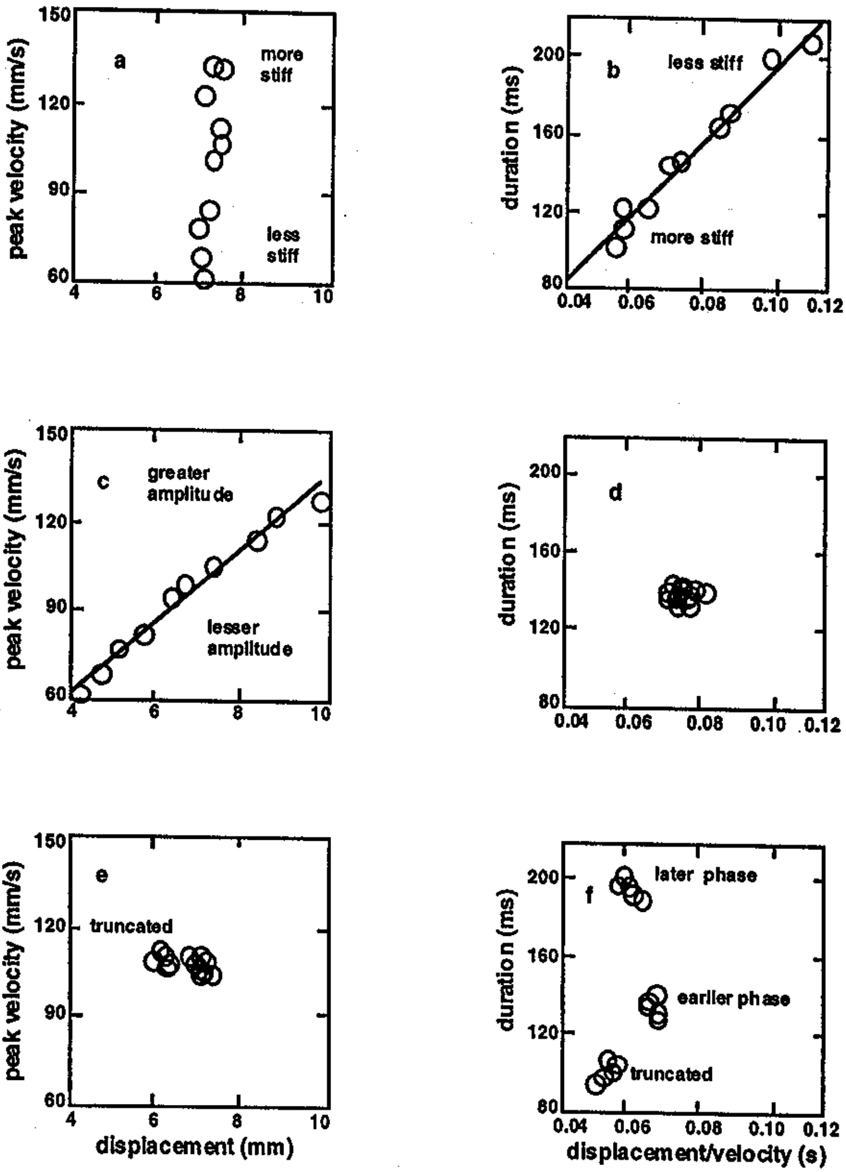

FIGURE 1. Kinematic manifestations of accenting if accenting is achieved by variation in (a,b) stiffness of an oscillatory system, (c,d) in amplitude, or (e,f) in phasing of gestures. (Adapted from Beckman & Edwards, 1992. See text for further explanation.)

According to the stiffness hypothesis, stressed and unstressed gestures should differ in peak velocity, but not in displacement (Figure 1a). This is because a change in k changes the value of ω but not of A. (Notice that this is not exactly the finding of Ostry et al. or of Kelso et al. described above and ascribed to a change in stiffness.) Further, because the peak velocity of the gesture will increase with an increase in k, with displacement held constant, unstressed gestures will be associated with smaller displacement/velocity ratios and shorter durations than stressed gestures (Figure 1b). If, instead, talkers stress gestures by increasing only their amplitudes, peak velocity (ωA) and displacement (A) will change proportionally. Therefore, gestures for stressed and unstressed syllables will fall on a common line relating displacement to peak velocity with slope ω (Figure 1c). Because the two measures change proportionally, the ratio of the one to the other will not change with stress variation, and gesture duration will not change (Figure 1d). If, finally, talkers change the phasing of sequential stressed gestures by reducing overlap, gestures will not change in velocity or displacement (unless highly overlapped unstressed gestures are truncated by following ones; Figure 1e). Because displacement and velocity do not change, their ratio does not change either (except, again, with truncation), but the measured duration of the stressed gestures will be longer (Figure 1f).

Beckman and Edwards examined kinematic measures of productions of the target syllable "pop" in the utterances below:

1. Pop, opposing the question strongly, refused to answer it.
2. Poppa, posing the question loudly, refused to answer it.
3. Poppa posed the question loudly and then refused to answer it.

This gave them a comparison of an accented, intonational phrase final syllable (sentence 1), an accented nonfinal syllable (sentence 2) and an unaccented syllable preceding a nuclear accent on "posed" (sentence 3). Overall, their kinematic (jaw-movement) data most closely favored the third, phasing hypothesis—a result consistent with Krull's (1989) findings, summarized earlier, of shallower locus equation slopes for stressed than unstressed syllables. However, the data were not fully consistent with any of the three hypotheses. In particular, whereas a change in phasing should not be associated with a change in movement velocity, jaw opening movements did show differences as a function of accent. The investigators judged them small relative to displacement changes, and ascribed the displacement changes, therefore, to truncation due to a change in phasing rather than to a true change in gesture amplitude.

A subsequent report by Beckman and Edwards (in press) examines utterances 4b and 5b below, produced in answer to questions 4a and 5a, respectively.

4a. Was her *mama* a problem about the wedding?
  b. Her POPPA posed a problem
5a. Did *his* dad pose a problem as far as their getting married?
  b. HER poppa posed a problem.

In these utterances, both syllables of "poppa" were examined. The final syllable is unaccented and lexically unstressed. The first syllable is lexically stressed in both utterances, but accented only in 4b. In these sentences, the accents express a contrast with information in the preceding question. In the findings on these utterances (with the same speakers as in the earlier study), there generally was overlap in measures of lip displacement and velocity for the two lexically stressed syllables. Striking kinematic differences were seen only comparing these two syllables to the unaccented, lexically unstressed final syllable of "poppa." The conclusion in this paper is that, whereas kinematic differences may be seen between accented and unaccented lexically stressed syllables, the differences are not consistent across talkers and utterances. The most consistent marker of accented words is the pitch accent on the word. Kinematic differences are "ancillary" to the pitch accent difference; perhaps kinematic differences arise sometimes to accommodate the pitch contour. Large consistent kinematic differences do differentiate lexically stressed and unstressed words; accordingly, stress is marked differently at different levels of a prosodic hierarchy. If a syllable is stressed lexically—that is, if it is the head of a metrical stress foot (see, e.g., Selkirk, 1980)—its stress will be marked kinematically. (For the two talkers whose data are discussed, the conclusion was that lexical stress was achieved by a change in stiffness.) If a lexically stressed word receives a sentence accent, the accent will be implemented by a pitch accent on the word, and, if necessary, something will be done (a change in stiffness for one of the two talkers, a change in phasing for the other) to lengthen the gestures to accommodate the accent.

This account is very neat and very interesting. It is not entirely clear, however, that it is consistent with other findings. In particular, Summers' (1987) findings, summarized above, of consistent kinematic correlates of stress were obtained from three talkers who produced contrastive stress either on the target CVC utterance or on the word before it in a carrier sentence. These words would have been heads of stress feet that were accented when contrastively stressed. In unpublished research, Fowler, Gracco, Vatikiotis-Bateson, and Romero (in press) find large and consistent kinematic differences among productions of a target word "pop" that is either accented, because it provides the new information in an answer to a question or, unaccented, when another word in the sentence, either before the target word or after it, is accented. For these sentences, "pop" always is stressed lexically. Of course, it remains possible that these kinematic correlates of sentence accents are "ancillary" to production of pitch accents; however, they were found to be consistent and reliable across talkers and utterances.

METHOD

Subjects and Speech Materials

The present report provides another data set from three native speakers of English, the same three talkers as in Fowler et al. (in preparation). In the data set reported on here, utterances are the six listed below. In one set, the target word (underlined) appears early in the utterances, and it is either contrastively stressed (capitalized) or it precedes or follows contrastive stress on another word. In the second set, the target word appears late in the sentence and it is either contrastively stressed or it precedes or follows contrastive stress on another word.

6a. He's POPE John not VICAR John.
b. He's pope JOHN not pope FRED.
c. HE's pope John the man in blue's pope Fred.
7a. Her CIGAR'S in the ashtray but her PIPE'S in her pocket.
b. HIS pipe's in the ashtray but HER pipe's in her pocket.
c. Her pipe's OUT of the ashtray but her pipe's IN her pocket.

Measurements

We measured various acoustic variables: vowel duration, measured as the voiced interval in each word, and average fundamental frequency (F_0), and average F_1, F_2, and RMS amplitude during the vowel of the target syllables. In addition, we measured numerous kinematic variables. Discussion here will be limited to measures of lip-aperture opening duration, displacement, and peak velocity.

Movements of the upper lip, lower lip, and jaw for one subject (VG) were obtained using strain gauge transducers on a head-mounted frame (see Barlow, Cole, & Abbs, 1983). For the other subjects, movements were obtained from light emitting diodes (subjects EB and JS). Signals were recorded on FM tape and were digitized off line with 12 bit resolution. The sampling rate for the movement signals was 500 Hz. Audio signals were filtered at 4.8 kHz and sampled at 10 kHz. Following digitization, movement signals were low passed filtered at 25 Hz using a procedure that effectively eliminates time delays. Finally, the lip and jaw signals were combined in software to obtain a signal reflecting lip aperture. Durations of opening and closing movements, displacements, and peak velocities served as the data to be described below.

RESULTS

Acoustic Measures of Contrastive Stress

Figure 2 shows the fundamental frequency contour of typical productions of sentences 6a-to-6c. The accents on contrastively stressed syllables are clearly visible. The second contrastively stressed syllable in each sentence ("vic," "Fred," and "blue," in 6a-c, respectively) has a lower peak than the first. The fundamental frequency patterns for typical productions of the "pipe" sentences were similar to those in Figure 2.

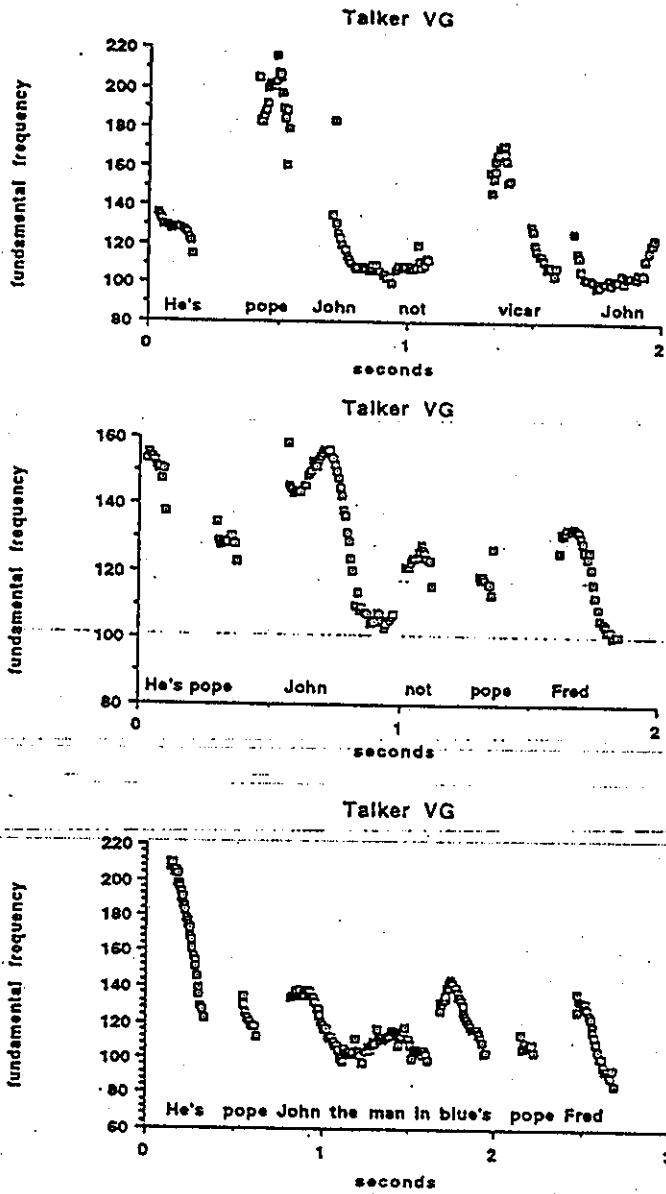

FIGURE 2. Fundamental frequency contour of typical production of sentences 6a-c.

Early Contrastive Stress

By far, the most salient acoustic marker of early contrastive stress was fundamental frequency. In analyses of variance, the *F* value comparing the average fundamental frequencies during the vowels of the three sets of productions of "pope" exceeded 200 for all three talkers. In each data set, average fundamental frequency on the accented word was higher than that in either unaccented word. No other acoustic or kinematic measure was as reliable. The only other acoustic measure that was significant for all three talkers was RMS amplitude; further, it showed the expected pattern of a higher value for the accented word for just two of the three talkers. The patterning of F_1 (lower for unaccented "pope") and F_2 (higher for unaccented "pope") may reflect centralization of the /o/ component of the diphthongized vowel of the word. This pattern was present for two of the three talkers, but the pattern on F_1 differs from that reported by Tiffany (1959), who took measures of stressed and unstressed vowels one quarter of the way through each vowel.

Late Contrastive Stress

In the "pipe" sentences, in which the target word was late and was the second of two contrastively stressed syllables, although fundamental frequency differed reliably as a function of accent for all three talkers, and differed such that the accented word had the highest average fundamental frequency, it was not the most reliable acoustic marker of contrastive stress (Talker JS: $F(2,27) = 10.89$; VG: $F(2,27) = 37.10$; EB: $F(2,27) = 15.75$, $ps < 0.001$). The remaining acoustic measures are significant for all three talkers, but not always for the same reason. For two of the talkers, F_1 was lowest for the accented syllables, and for all three talkers, F_2 was lowest. This is the same pattern of changes found by Tiffany (1959). Duration and RMS amplitude showed different patterns across the three talkers. If we ask what variable both patterned such that the accented word was distinguished from the unaccented productions and was the most reliably distinct, that variable is F_2 for JS ($F(2,27) = 15.75$, $p < 0.001$), RMS amplitude for VG ($F(2,27) = 55.57$, $p < 0.001$), and fundamental frequency for EB ($F(2,27) = 15.75$, $p < 0.001$).

Kinematic Measures of Contrastive Stress

Early Contrastive Stress

Opening duration, displacement, and peak velocity pattern in the same way for the three talkers. Opening durations are longest for the accented syllable (JS: $F(2,27) = 142.75$; VG: $F(2,27) = 48.4$; EB: $F(2,27) = 19.02$), displacements are largest for the accented syllable (JS: $F(2,27) = 171.03$; VG: $F(2,27) = 56.45$; EB: $F(2,27) = 34.4$), and velocities are highest (JS: $F(2,27) = 82.63$; VG: $F(2,27) = 10.4$; EB: $F(2,27) = 6.81$). There are, for these speakers, then, highly reliable kinematic correlates of accent. Too, somewhat surprisingly, these did not, for any of the talkers, give rise to an acoustically longer duration vowel. Accordingly, if the reason for the larger accented than unaccented gestures was to better accommodate the pitch accents of Figure 2, the effort was not successful.

Turning to the dynamical means by which stress accent might have been achieved by the talkers, as depicted in Figure 1, I can rule out a change in stiffness as an important mechanism. Figure 3 shows regression lines fit to sentences 6a-c. Clearly the data do not resemble the idealized picture of Figure 1a. (Separate regression lines fit to each sentence separately (Table 1) do not show a shallower slope for accented words for any of the three talkers. This is consistent with the suggestion of Beckman and Edwards (1992, in press) that accenting lexically stressed words is not like the comparison of lexically stressed to unstressed syllables in the research of Ostry et al. and Kelso et al.)

Talker EB (Figure 3b) shows a pattern similar to that of Beckman and Edwards' (in press) talkers in which points for accented and unaccented syllables overlap considerably. However, JS and VG (Figures 3a and c) show a clean and nearly clean separation, respectively. The patterning in their data is most consistent with a hypothesis that the amplitude of gestures (Figure 1c) is increased under contrastive stress. However, neither VG nor EB shows a consistent relation between variation in the displacement/velocity ratio and duration, a finding also predicted by a controlled increase in gesture amplitude (Figure 1d). JS does show a consistent relation however ($R^2 = 0.65$), with a steep line relating a clump of points for the unaccented words to a clump for the accented words (Figure 4). This pattern looks most consistent with an interpretation of a change in stiffness (Figure 1b), an interpretation, however, ruled out above on other grounds.

Late Contrastive Stress

As for the measure of fundamental frequency, kinematic differences between accented and unaccented productions of "pipe" are generally less reliable than those for "pope" in the early sentence position. Measures of opening duration (JS: $F(2,27) = 5.39$; VG: $F(2,27) = 18.49$; EB: $F(2,27) = 15.27$) are uniformly significant, but only EB and VG show the expected pattern with accented productions longest. Measures of opening displacement are significant only for JS and EB (JS: $F(2,27) = 64.33$; VG: $F(2,27) = 2.78$, $p = 0.08$; EB: $F(2,27) = 21.45$), and the measure patterns numerically as expected only for JS and VG. Opening velocity is uniformly significant and it patterns as expected for all three talkers (JS: $F(2,27) = 116.65$; VG: $F(2,27) = 8.29$; EB: $F(2,27) = 21.12$).

Displacement-peak velocity relations are shown in Figure 5. Again no subject shows the pattern expected if stiffness were reduced under constrastive stress.

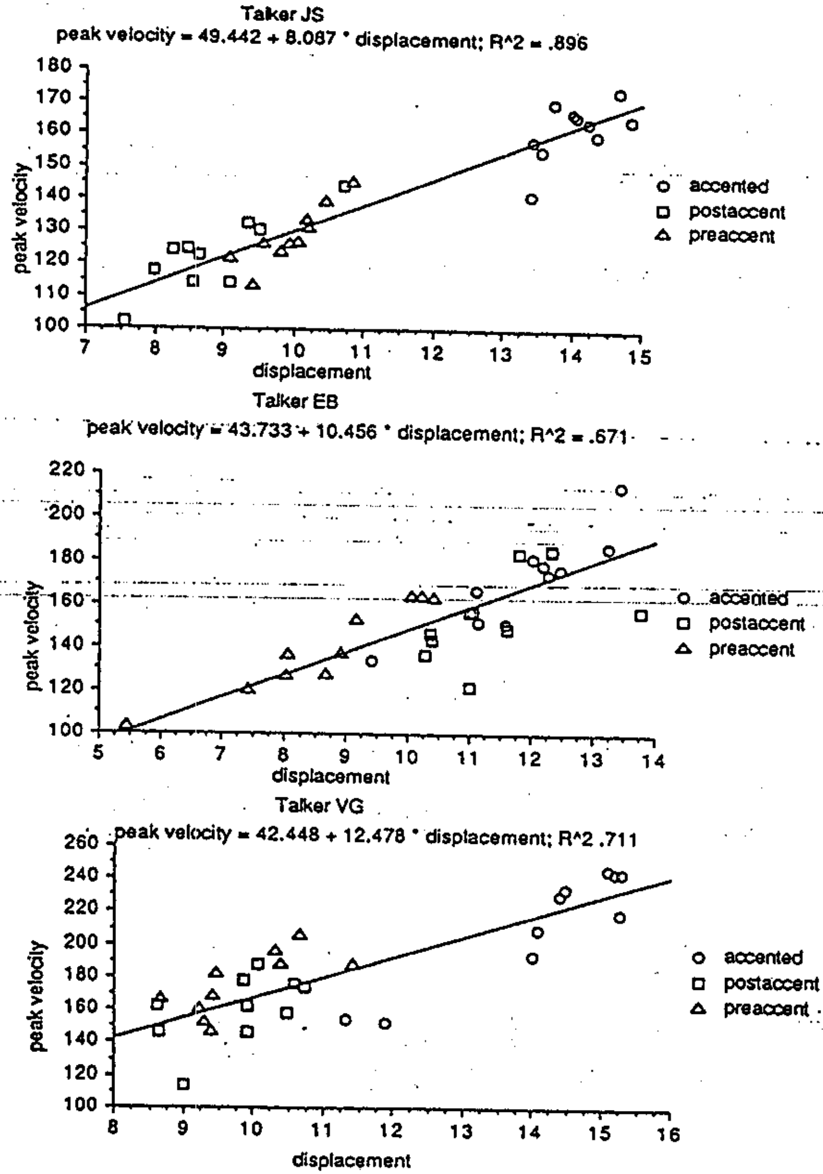

FIGURE 3. Scattergrams and regression analyses of displacement predicting peak velocity for the three talkers' productions of sentences 6a-c (early contrastive stress).

TABLE 1. *Slopes of regression lines relating displacement and peak velocity. Nonsignificant values (p > .0 05) are in parentheses.*

	Pope sentences			Pipe sentences		
	Accented	Post-accented	Pre-accented	Accented	Post-accented	Pre-accented
JS	11.6	11.3	16.0	(8.1)	8.6	(5.1)
VG	23.8	(15.0)	17.5	21.2	14.9	(10.4)
EB	17.2	21.9	13.2	14.4	10.8	15.4

As for the "pope" sentences, JS shows a close fit of points to the line and no overlap between accented and unaccented words. Both EB and VG show overlap, here perhaps an indication that there is little separation kinematically between contrastively stressed and unstressed words. (JS is the only one of the three subjects to show overall reliable differences in both velocity and displacement favoring the accented word in the analyses above.) Only JS shows a pattern that is interpretable in the context of the mechanisms depicted in Figure 1. His pattern conforms most closely to that expected if the major dynamical parameter that is changed under stress is amplitude. This interpretation does not fit the data for EB and VG, but then they distinguish the syllables only weakly or not at all on one of the relevant kinematic measures.

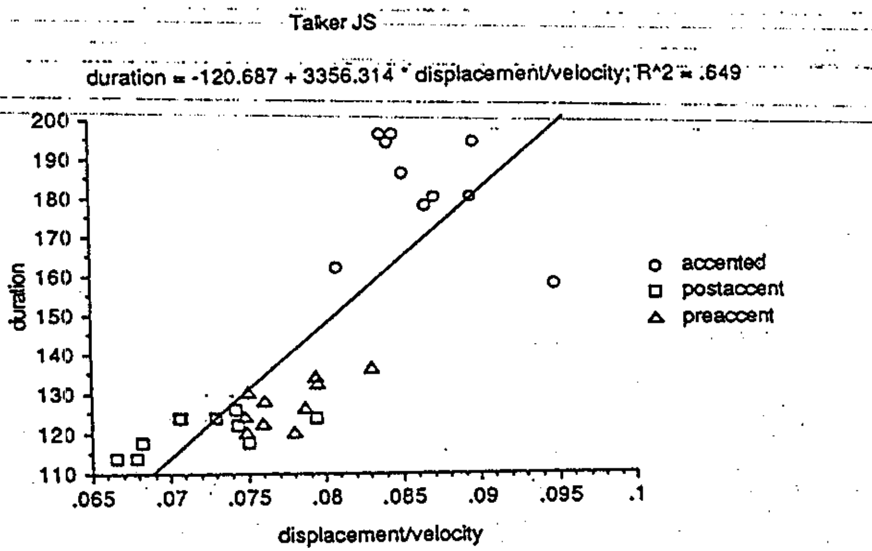

FIGURE 4. Duration predicted by the displacement/peak velocity ratio of talker JS on sentences 6a-c.

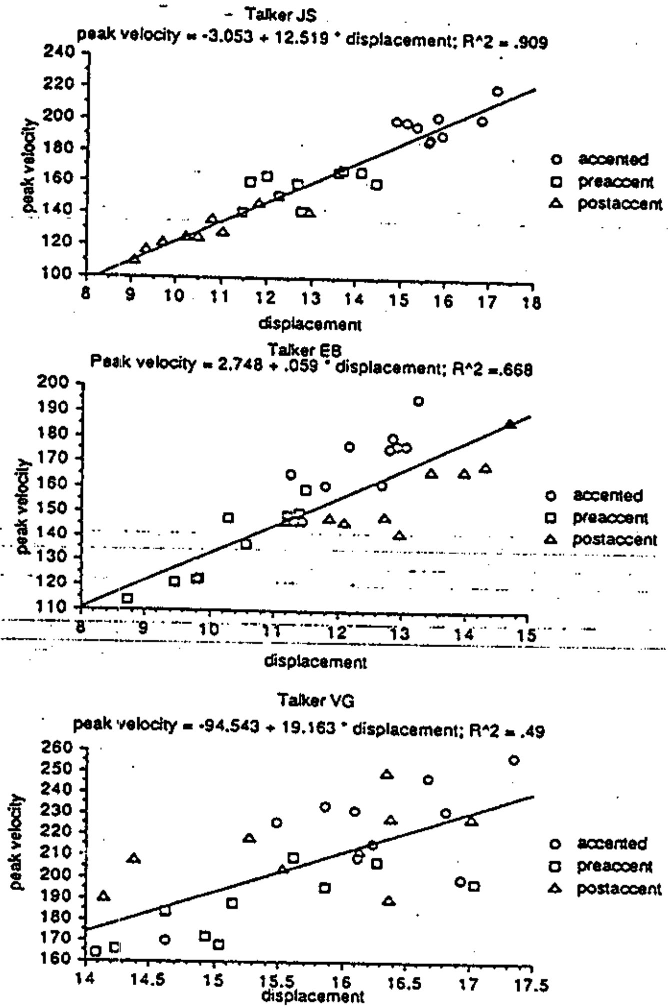

FIGURE 5. Scattergrams and regression analyses of opening displacement predicting peak velocity for the three talkers' productions of sentences 7a-c (late contrastive stress).

The relationship between the displacement/velocity ratio and the duration of the opening gesture is significant only for JS (Figure 6). However, the scatterplot is not consistent with any of the patterns in Figure 1. There is considerable overlap in points for accented and unaccented words.

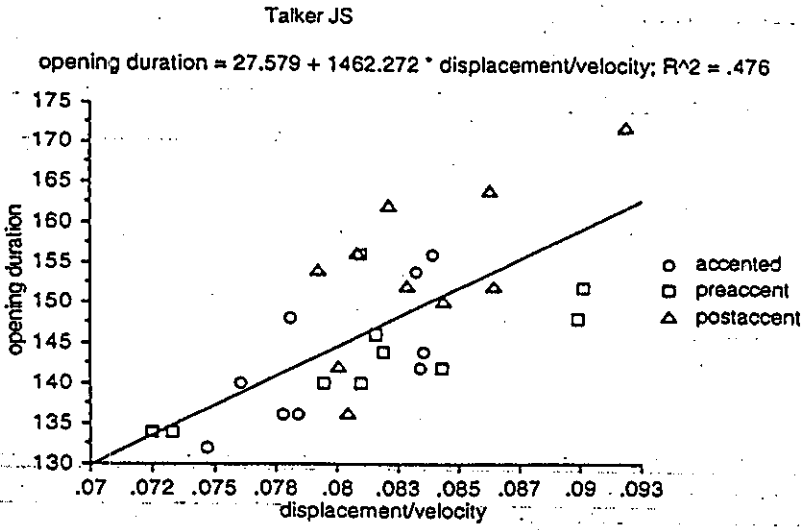

FIGURE 6. Duration predicted by the displacement/peak velocity ratio of talker JS on sentences 7a-c.

Pre- and Post-accented Words

We had included sentences 6b and 6c and 7b and 7c both to provide comparisons with the accented versions of each target but also to see whether unaccented words preceding and following a major stress or accent were produced differently. In brief, we found no systematic differences between unaccented words preceding or following an accented word in either acoustic or kinematic measures.

DISCUSSION

The data permit a few conclusions. A positive conclusion is that contrastive stress accents are reliably marked by pitch accents in both early and late positions in the sentence. These are not the only reliable correlates of accentuation, however, especially for early accents. There are also highly reliable kinematic correlates of accents. Whereas it may be the case, as Beckman and Edwards (in press) suggest, that these are subsidiary to the pitch accent, for a few reasons, I am not convinced that this is the most plausible interpretation. First, the present data do not conform to a hypothesis that, kinematically, stressing is achieved in ways that increase acoustic syllable durations in the most straightforward way possible. As Figure 1 shows, changes in stiffness and phasing should increase the acoustic duration of a syllable. But our data do not fit those patterns well. This is not to say that gestures were not larger for accented than unaccented words; they were, reliably so. Rather it is that the kinematic consequences were not confined to amplitude changes and their kinematic correlates that might be expected on the assumption that speakers are intending only to lengthen a syllable. Another point that perhaps not too much should be made of, because it is unusual, is that, for these subjects, acoustic duration was not a reliable indicator of stress accent. Related to these considerations is that we took between nine and eleven kinematic measures from our subjects, the lip aperture opening measures already described, compatible measures of closing, measures of respiratory activity using Respitrace and, for two subjects, measures of intraoral pressure during /p/. JS showed significant effects of accent with the expected patterning on all but two of the kinematic measures on the early accented sentences, VG on all but three, and EB on six of ten measures. A final point is that Kelso et al. (1983) found larger amplitude movements of the finger accompanying accented as compared to unaccented productions of the strong syllable "stock." Together these findings appear most consistent with the older "global effort" hypothesis. Perhaps it is not that kinematic adjustments occur to accommodate a pitch accent, but rather that the perceptually salient pitch accent highlights global effort increases for the listener.

What should be made of the observation that the data did not conform to predictions of any of the three ways, illustrated in Figure 1, in which talkers might produce stress accents simply from a dynamical systems perspective? Incompatibility with predictions can have several origins. One likely reason is that the simple oscillatory system used to generate the predictions of kinematic correlates of stress accent is not realistic. As noted earlier (see, especially, footnote 1), this possibility has been considered also by Kelso et al. (1985). Another reason, however, is that the model oscillator represents a presumed control system for vocal tract actions and does predict the effects on action of the biomechanics of the vocal tract itself. These effects, with an origin peripheral to any oscillatory control system, may make model testing difficult.

Differences in the Magnitude of Accentuation in the Sentence Sets

Correlates of stress accent were generally weaker for the later accented word "pipe" than for the earlier word "pope." Our sentence sets 6 and 7 do not permit a clear interpretation of this difference. It may be a consequence of general articulatory dwindling early-to-late in an utterance for which weak evidence has been reported in the literature (Bell-Berti & Krakow, 1991; Fowler, 1988; Krakow, 1993; Vatikiotis-Bateson & Fowler, 1988; Vayra & Fowler, 1992). However, other interpretations are possible. The utterance sets under examination here both consisted of two intonational phrases, and the late accented word was always in the second phrase. Perhaps a nuclear accented word in an intonational phrase following one in an earlier phrase is reduced in magnitude. Third, the second accented words in both sentence sets are redundant as compared to the first accented word, and the redundancy may underlie the reduction (cf. Fowler & Housum, 1987; Lieberman, 1963). That is, in a sentence like "He's POPE John not VICAR John," the listener knows, after hearing "not," that an accented word will be produced that contrasts in some way with the first accented word. Further, it is very likely that the contrasting word will be in the same broad semantic category as the first one.

Two observations help to distinguish among the interpretations. First, the later of two nuclear accented words need not be smaller in pitch accent than the first. In an utterance in which a talker produces a word substitution error and then corrects it (e.g., "It's a pen holder...I mean a pipe holder"), the correction is accented, and its pitch accent has a higher peak and a higher average fundamental frequency than the accented word that it corrects. This outcome is not consistent with a hypothesis that the second of two nuclear accented words in sequentially produced intonational phrases *must* be reduced. A second observation may help to distinguish these remaining hypotheses. This observation derives from a data set described in detail in Fowler et al. (1993). In this study, the same talkers as in the present study produced answers to questions in which the target word "pop" either provided the new information in the answer or provided given information. Across sentence sets, "pop" appeared in four positions in the answers, early (initial) to late (final). In these sentences, accented "pop" did not provide redundant information; further, when "pop" was accented, it was the nuclear accent in the answers, which were produced on just one intonational phrase. These utterances should provide a clean test of the hypothesis that there is a global dwindling of acoustic and kinematic correlates of accenting early-to-late in an utterance, or perhaps in an intonational phrase. In brief, however, there was no convincing evidence that the difference in acoustic or kinematic correlates of accented and unaccented, productions of "pop" decreased early-to-late in an utterance. Nor was there evidence that utterance final accented "pop" was less distinct from unaccented "pop" than were target words elsewhere in the utterance. The most viable interpretation of the difference in magnitude of markers of accenting in the "pope" sentences as compared to the "pipe" sentences, therefore, is that it reflects a difference in the redundancy of the accented word in the two sentences.

SUMMARY AND CONCLUSIONS

I interpret the present findings as showing that lexically stressed, accented words are distinguished from stressed but unaccented words in multiple ways. A salient acoustic marker of stress accent is the occurrence of a pitch accent on an accented word. However, accented words are also distinguished by supralaryngeal kinematic markers that, presumably, index the dynamical systems that are used to achieve and release constrictions for the component consonants and vowels of the accented words. These kinematic differences between accented and unaccented words themselves have acoustic consequences.

I found no simple way to characterize the kinematic differences in terms of a change in a single dynamical parameter. In this respect, findings are most consistent with suggestions that accenting reflects an overall increase in global articulatory effort. These conclusions are qualified, however, by recognition that kinematic measures may reflect operation of dynamical control systems as their effects are mediated by the biomechanics of the vocal tract anatomy and physiology.

No evidence was obtained in the data for a global dwindling in accentuation early to late in an utterance. The smaller effects of late than early accenting most likely reflect the redundancy of the later, as compared to the earlier, accented words in the particular utterances we asked talkers to produce.

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