KINEMATIC ANALYSIS OF COARTICULATION AND SPEAKING RATE

by

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INTRODUCTION

During speech production, the acoustic and kinematic properties of certain sounds and articulatory configurations are changed under the influence of adjacent sounds. This is termed "coarticulation." Previous studies have resulted in two competing theories of anticipatory coarticulation: 1) look-ahead or feature spreading models and 2) coproduction or frame models. The look-ahead model suggests that the anticipatory activity begins as soon as there are no competing requirements of the articulators, and is therefore relatively free to vary in its onset time (e.g., Henke, 1967). The coproduction model suggests that an anticipatory activity begins at a fixed time before the actual target (e.g., Bell-Bert and Harris, 1981). Recently, Perkell and Matthies (1992) proposed a hybrid model of coarticulation, which combines components of these two models. They suggested that there may be two phases to a lip protrusion gesture. The first phase involves a slow, gradual onset of protrusion that begins as early as permitted by the competing requirements of the articulators. The second phase is a more rapid protrusion movement, which is time-locked to the onset of the rounded vowel. The authors suggest that the maximum acceleration of the lip signal separates the two phases of the protrusion gesture.

Previous studies have examined coarticulation by manipulating intervocalic consonant durations before a rounded vowel, typically by changing the number of intervocalic consonants. The timing relationship of select movement, electromyographic, or acoustic events related to lip rounding are then analyzed. In the current study, intervocalic consonant durations were manipulated by having speakers produce utterances at systematically varied rates of speech. Stetson (1951) suggested that systematic modifications of rate may reveal the underlying control mechanisms which operate during speech production. Investigations into the manipulation of rate may therefore provide us with information regarding how the motor system is organized to coordinate the articulators for the complex movements required for speech.

METHODS

Six normal speakers served as subjects; 3 were considered "Young Normal" (YN) and ranged in age from 20 to 25 years; 3 subjects were considered "Older Normal" (ON) and ranged in age from 50 to 78 years. All subjects were native English speakers. Subjects produced the sentence "I see two and I see tea again," fifteen times at six different rates.

Rate was manipulated using a magnitude production task (c.f. Adams et al., 1993). Subjects produced the sentence at a self-selected normal rate of speech. Subjects were then asked to produce the sentence at two and four times their normal rate, one half and one quarter their normal rate, and maximally fast. Rate conditions were randomized for all subjects. Upper lip protrusion, transduced using strain gauges (Barlow et al., 1983), and the acoustic signal were digitized.

Upper lip protrusion was clearly detected as an upward movement of the signal during the production of "I see two," while the movement trace did not deflect upward during the production of "and I see tea again." This indicates that the observed lip protrusion was not inherent to the production of the consonant /t/, as has been proposed by Gelfer, Bell-Berti and Harris (1989). Rather, the trace deflection can be attributed to upper lip protrusion for the /u/ in "two."

The duration from the onset of upper lip protrusion to the acoustic onset of /u/ was measured and labelled "Movement Interval." Similarly, the duration from maximum upper lip acceleration to the acoustic onset of /u/ was measured and labelled "Acceleration Interval". "Consonant Duration" was measured as the time from the last glottal pulse of V1 (that is, /i/ in "see") to the first glottal pulse of V2 (that is, /u/ in "two").

RESULTS

Qualitatively, four distinct patterns of upper lip protrusion were observed, with patterns varying both within and between subjects. For some subjects, the pattern appeared to be dependent on rate, while for other subjects, the pattern was clearly not related to rate.

The most frequently occurring pattern was characterized by a smooth onset of upper lip protrusion, and a single velocity peak. A second pattern was characterized by double peaks in the velocity profile, with one velocity zero crossing. A third pattern was similar to this; however, there were two zero crossings in the velocity profile. The fourth, and final pattern was characterized by a very slow, irregular increase in velocity, that often hovered just above zero for an extended period of time. A weak trend indicated an increase in the multiple velocity peak patterns with slower rates of speech. However, this trend was not observed for all subjects. A slightly stronger trend indicated that Young Normal subjects exhibited fewer double zero crossings and a higher number of single-peaked productions than the Older Normal subjects. However, due to the small number of subjects in each age group, only limited conclusions can be drawn from such findings.

Based on quantitative results, the onset of upper lip protrusion was similar to that observed by Perkell and Matthies (1992). That is, movement onset typically began early, during or even before /i/ production in "I see", and appeared to be independent of rate. Perkell and Matthies hypothesized that various regression lines would be expected for pairs of values of acceleration interval and movement interval versus consonant duration, according to the three models of coarticulation discussed earlier. According to these authors, the look-ahead model predicts a positive slope for both plots, suggesting that both the acceleration interval and the movement interval vary with consonant duration. The coproduction or frame model predicts slopes of zero for both plots, suggesting that neither the acceleration interval nor the movement interval change with changes in consonant duration. The hybrid model proposes that the acceleration interval is constant across consonant durations, with a slope of 0, while the movement interval changes with consonant duration, with a positive slope.

In the current investigation, the relationship of both acceleration and movement intervals to consonant duration was examined using regression analysis. The R^2 values, provided in Table 1, indicate that regression accounted for between 0.7% and 78.2% of the variance. Because the variability cannot be accounted for with a low R^2, those values below 45% were not analyzed further.

The slope of movement interval versus consonant duration was substantially greater than 1 for all three Young Normal subjects and for Older Normal 2. This indicates that the onset of the protrusion gesture began earlier relative to the acoustic onset of /u/ as consonant duration increased. This finding does <u>not</u> support the coproduction model, in which protrusion onset would be time-locked to the /u/.

Subjects Young Normal 1 and Older Normal 2 demonstrated fairly high R^2's for <u>both</u> acceleration and movement intervals. Protrusion onset began earlier as consonant duration increased, as demonstrated by the slopes of the movement interval. Additionally, the slopes of the acceleration interval versus consonant duration were 0.952 and 1.250, for YN1 and ON2, respectively. This indicates that the maximum acceleration also occurred earlier relative to /u/ as the consonant duration increases. These findings, particularly for these two latter subjects, support the look-ahead model, which predicts that both onset and maximum acceleration of lip protrusion will begin earlier relative to /u/ as consonant duration increases.

DISCUSSION

These data indicate that the time of lip protrusion onset varies with the intervocalic consonant duration. As consonant duration increased, lip protrusion began earlier relative to the acoustic onset of /u/. This pattern was distinctly observed in four of the six subjects. This finding lends support to the look-ahead or feature spreading model, which suggests that movement for an upcoming segment may be initiated as soon as its onset does not interfere with the immediate articulatory requirements. It was also observed that the time of maximum acceleration of the protrusion gesture covaries with consonant duration, rather than remaining time-locked to the onset of /u/. Perkell and Matthies have proposed that maximum acceleration may be temporally related to the acoustic offset of the preceding vowel. This will be examined in further analyses of the data.

These data demonstrate that there are changes in the pattern of coarticulation with alterations in rate. It appears that the motor system allows for flexibility in timing lip protrusion as we manipulate speaking rate. Previous research on coarticulation, in both normal and disordered speakers, has typically not controlled for speaking rate. Therefore, we need to interpret the literature with caution. Future studies should take into account the effect of rate on the timing of coarticulation.

REFERENCES

Adams, S.G., Weismer, G. and Kent, R.D. (1993). Speaking rate and speech movement velocity profiles. Journal of Speech and Hearing Research, 36, 41-54.

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

Bell-Berti, F. and Harris, K.S. (1981). A temporal model of speech production. Phonetica, 38, 9-20.

Gelfer, C.E., Bell-Berti, F. and Harris, K.S. (1989). Determining the extent of coarticulation: effects of experimental design. Journal of the Acoustical Society of America, 86, 2443-2445.

Henke, W.L. (1967). Preliminaries to speech synthesis based on an articulatory model. Proceedings of the 1967 IEEE Boston Speech Conference, 170-171.

Perkell, J.S. and Matthies, M.L. (1992). Temporal measures of anticipatory labial coarticulation for the vowel /u/: within- and cross-subject variability. Journal of the Acoustical Society of America, 91, 2911-2925.

Stetson, R.H. (1951). Motor Phonetics (North-Holland, Amsterdam).

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Table 1.

		Slope	R^2
YN1	Acceleration Interval	0.952	69.9%*
	Movement Interval	2.350	59.8%*
YN2	Acceleration Interval	0.390	9.2%*
	Movement Interval	1.090	56.1%*
YN3	Acceleration Interval	0.238	2.2%
	Movement Interval	2.640	78.2%*
ON1	Acceleration Interval	0.548	0.7%
	Movement Interval	1.480	12.4%*
ON2	Acceleration Interval	1.250	45.0%*
	Movement Interval	1.650	73.3%*
ON3	Acceleration Interval	0.446	4.3%
	Movement Interval	1.170	12.6%*

* $p < .05$

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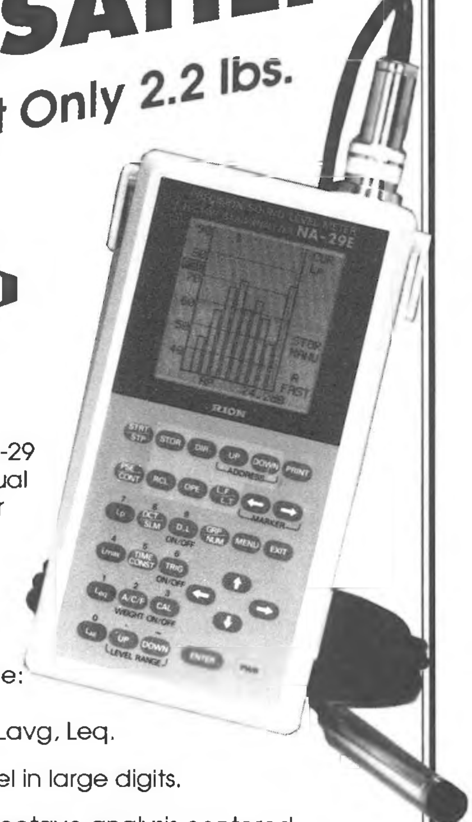

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