

Patterns of interarticulatory coordination within the syllable



Patrizia Bonaventura
Department of Communication Sciences
Case Western Reserve University

ABSTRACT

Interarticulatory coordination patterns were observed in movements of a concurrent articulator, the tongue blade, to the crucial articulator for the production of place in selected syllables containing labiodental fricatives and alveolar nasals. The coordination of the lower lip with tongue blade, and the coordination of the tongue tip with the tongue blade have been studied in the production of syllables containing labiodentals and alveolar phones, respectively. The goals of the study were to verify a) whether stable patterns of speed with respect to excursion of movement ('icebergs', Fujimura, 1981, 1996), were found in concurrent articulators to the crucial one for production of place, in realizations under different prosodic conditions, and b) whether such stable portions would vary proportionally to the increase in amplitude of the vertical jaw movement, selected as a measure of the magnitude of the syllable (Bonaventura, 2003). The study is based on the general hypotheses that the consonantal gestures are encoded and realized separately from vowel-to-vowel gestures (Ohman, 1966) and on the C/D model assumption that consonantal movements are associated with inherent temporal characteristics, specifying their timing with respect to the vocalic movements, as an intrinsic time pattern (Fujimura, 2003). The hypotheses have been tested by analyzing articulatory recordings from cinefluorographic data, based on read dialogues (Erickson et al., 1998). 'Icebergs' patterns were found in the tongue blade movements, concurrent articulator to the lower lip and to the tongue tip, for production of the digits 'five' and 'nine' respectively, both in initial and final demissyllable. The 'iceberg' patterns found for the tongue blade movements were similar to the ones previously extracted the crucial articulator tracings, showing a linear dependence of slope on the total excursion of the demissyllable. Also, variations in the linear patterns due to outliers, found previously for the 'lower lip movements especially in final demissyllable, were not present in the tongue blade movement patterns.

INTRODUCTION

THE CONVERTER/DISTRIBUTOR MODEL AND ARTICULATORY INVARIANCE

The presence of relatively stable portions of articulatory movements of selected articulators within syllables is investigated in this study. Dynamic movements are considered as crucial descriptive characteristics of speech signals, according to the C/D model of phonetic representation of speech utterances (Fujimura, 2003a, b). The Converter/Distributor (C/D) Model uses syllables instead of phonemes as the concatenative units of speech signals. It represents the rhythmic organization of an utterance by a magnitude-controlled syllable-boundary pulse train. Based on the magnitude distribution of the syllable pulses, syllable durations are computed. Assuming temporal gaps between consecutive syllables to represent the boundary pulse magnitudes, syllable-boundary triangles are placed in time as contiguous series. The phonetic magnitude of each boundary as well as syllable, is continuously variable according to various utterance factors.

ICEBERG PATTERNS

Fujimura [1986], based on microbeam data, suggested that a certain part of articulatory movement patterns was characteristically constant for a given demissyllable, when stress conditions varied. The speed of movement of the crucial articulator (responsible for an obstructed gesture) crossing a fixed height threshold (relative to the occlusal plane, for a given speaker) was identified as such a relatively invariant pattern. The time function representing the first time derivative (velocity) of a flesh-point (pellet) position resembled the tip of the floating iceberg. Later, Fujimura proposed the C/D model as a new comprehensive theory of phonetic implementation. It assumed (like Ohman [1967]) that a sequence of vowel gestures for syllable nuclei formed a slowly changing syllable gesture (phonetic status contour) as an aspect of what is called base function, on which local quick gestures for consonants (elemental gestures) are superimposed, according to syllable feature specifications. The C/D model further assumes that each elemental consonantal gesture constitutes a fixed ballistic motion pattern, which, as a passive response, is evoked by a time-shifted replica (onset pulse, coda pulse, etc.) of the syllable pulse as the excitation. For computation of the phonetic implementation, all elemental gestures for consonants as demissyllabic constituents (i. e., onset, coda, or syllable affix) of the syllable, are stored in an impulse response function (IRF) table (Fig. 1).

METHOD

The 'New Red Pine 96' corpus includes dialogues of the form "Is it 995 Pine Street? No, it's 985 Pine Street. Is it 995 Pine Street? No, it's 995 Pine Street." Such question-answer exchanges include reference digits (in questions) and corrected and uncorrected digits in correcting utterances both spoken by the subject. The corrected digit in the 3-digit sequence was emphasized, so they will be referred to as 'emphasized', whereas the uncorrected digits, in the correcting utterances, will be referred to as 'unemphasized'. Productions by one subject were observed, native speaker of Midwest American English.

The articulatory data were acquired at the University of Wisconsin by the X-ray Microbeam system. The data consist of articulatory records, obtained by automatically tracking the movement of gold pellets attached on selected points of articulatory organs. The positioning of the pellets is illustrated in Figure 2.

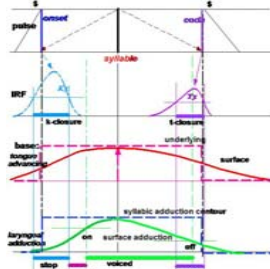


Figure 1: X/D (C/D diagram) (courtesy of Prof. O. Fujimura)

One implication of the C/D model is that the evoked elemental gesture is amplified, without changing the shape of the local time function, according to the magnitude of the syllable occurring in the utterance, because it is a linear response to the syllable pulse excitation (shifted in time for the syllable margin).

This assertion does not contradict the iceberg concept, since the consonantal movement should change according to the change of the syllable magnitude under emphasis or other prosodic conditions, contrary to the iceberg concept that a fixed part of the movement function should not be affected. It can be shown mathematically, however, that this is not necessarily a contradiction (Fujimura 1996). Depending on the time function for the IRF, the speed of crossing a fixed threshold position can be constant when the function is amplified by a multiplication constant. Exponential functions have such a property. Bonaventura (2003) has provided quantitative data about the existence of 'icebergs', using a read speech articulation material. 'Icebergs' had been observed initially on small sets of data (Fujimura, 1986), therefore the new study extended the observation to a larger corpus of a few selected demissyllables, to test the proposed concept against systematically collected data. Further issues were tested, related to the existence of icebergs, such as whether similar slope invariance was found in initial and final demissyllable, given the expectation that important prosodic effects, like 'phrase final elongation', affect more markedly the final, than the initial demissyllable.

PHRASE FINAL ELONGATION

Phrase-final elongation is a phonetic phrase boundary effects, consisting in rhyme elongation in phrase-final position. The elongation might cause a general decrease in velocity of all gestures in demissyllables in phrase final position, or it could create a pause, either a period of silence or period filled with residual voicing and other articulatory gestures. Currently available articulatory data are not sufficient to determine which model should be used. Bonaventura [2003], along with Mitchell's thesis (2000) and Menezes' dissertation [2003], attempt to provide empirical data for developing a quantitative model. The phrase final elongation was observed in the present study in the tongue blade patterns occurring at phrase boundary.

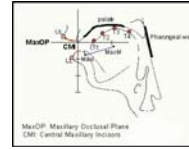


Figure 2: Pellet configuration (Nadler et al., 1987)

ICEBERG ANALYSIS

Curves at iceberg threshold were measured and extracted from the tracings of the tongue blade, as a concurrent articulator to the crucial articulator for place production in the digits in the dialogues, 9 and 5. These words are monosyllabic, they share the same obstructed articulator crucial for place, in initial and final demissyllable (lower lip for 'five' and Tongue tip for 'nine'), and they share the same vocalic nucleus (the diphthong /aj/).

Iceberg curves were drawn in different colors in the following figures, according to different emphasis conditions: black curves indicate digits in reference utterances, green curves indicate uncorrected digits, and red curves indicate corrected digits in correcting utterances. (see Fig. 3 - 6).

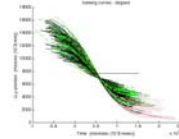


Figure 3: Speaker DE3, word 'five', 340 curves at iceberg threshold—initial demissyllable, tongue blade, vertical displacement

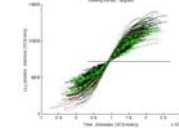


Figure 4: Speaker DE3, word 'five', 340 curves at iceberg threshold—final demissyllable, tongue blade, vertical displacement

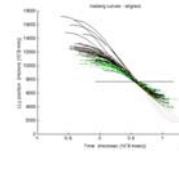


Figure 5: Speaker DE3, word 'nine', 70 curves at iceberg threshold—initial demissyllable, tongue blade vertical displacement

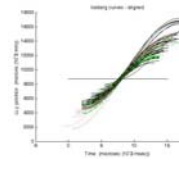


Figure 6: Speaker DE3, word 'nine', 72 curves at iceberg threshold—final demissyllable, tongue blade vertical displacement

Presence of invariance of iceberg slope, with respect to excursion distance, was tested by obtaining scatterplots of velocity vs. excursion. Excursion primarily reflects the vocalic position in the base function, since the consonantal gesture is usually saturated. The C/D model suggests that there may be some dependence of the speed at each phase of the movement on the total excursion, and such dependence may be reflected also in the slope at a constant position threshold crossing as the iceberg method examines. Again, digits in different emphasis conditions were differentiated by color and shape of the markers on the scatterplots (red indicated emphasized, green unemphasized, and black reference digit). The scatterplots indicate a linear relation between speed and excursion. (see Fig. 7 - 10).

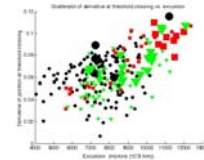


Figure 7: Speaker DE3, scatterplot showing maximum speed vs. excursion for 340 curves at iceberg threshold, initial demissyllable, tongue blade vertical displacement, word 'five'

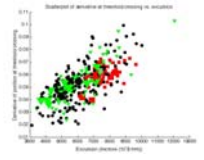


Figure 8: Speaker DE3, scatterplot showing maximum speed vs. excursion for 340 curves at iceberg threshold, final demissyllable, tongue blade vertical displacement, word 'five'

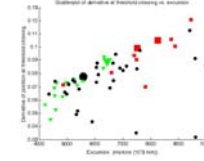


Figure 9: Speaker DE3, scatterplot showing maximum speed vs. excursion for 70 curves at iceberg threshold, initial demissyllable, tongue blade vertical displacement, word 'nine'

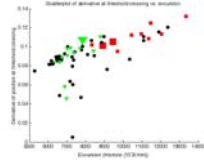


Figure 10: Speaker DE3, scatterplot showing maximum speed vs. excursion for 72 curves at iceberg threshold, final demissyllable, tongue blade vertical displacement, word 'nine'

RESULTS

The scatterplots show an effect of excursion, i.e. syllable magnitude, on the threshold crossing slope. However, this effect does not seem systematic for tongue blade vertical displacement, as it was found for the lower lip and tongue tip in 'five' and 'nine' respectively, in previous studies (Bonaventura, 2003). Prosodic effects in terms of alteration of the linear pattern in phrase final demissyllable, present for the lower lip in the same position (Bonaventura, 2003), were not found for the tongue blade movement.

DISCUSSION

The present study provides evidence that iceberg patterns are not present in concurrent articulator movements to the crucial articulator for /f/, /v/ and /n/: these findings support the C/D model hypothesis that a systematic relationship between excursion and speed is present only in the movement of the crucial articulator for place in each demissyllable. The present results show that alternative ways of measuring relative timing of concurrent articulator movements with respect to the crucial articulator displacement and to the displacement of the vocalic gestures, have to be investigated. The low influence of the prosodic effects on the consonantal articulator displacement might be due to the fact that phrase final elongation is not very prominent in the corpus analyzed, which contains read dialogues.

Further studies will focus on verification of the existence of stable patterns for other concurrent articulators, and on attempt to model the iceberg curves for each articulator and demissyllable location (initial or final), in order to test the hypothesis of existence of individual articulatory control function for each elemental gestures, which are magnified according to the syllable strength.