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B. STUDIES OF LABIAL ARTICULATION*

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Our interest in the motor behavior of the lips in speech production has necessitated the development of a descriptive framework in terms of which arbitrary lip configurations can be represented, a measure of labialization that incorporates a correction for the jaw-dependence of labial shape and a method for quantifying the dynamic aspects of lip movement. This preprint deals mainly with some of these methodological questions. A discussion of the spatio-temporal organization of labial articulation in various phonetic contexts will be presented at the meeting.

Data acquisition

The data on lip activity in speech have been obtained from 16 mm films which were made in cooperation with Henry Soron of the AFCRL, Bedford/Mass., USA (1). The films were taken at a speed of 128 frames per second and synchronized with tape recordings of the speech. Simultaneous frontal and lateral views were taken. To improve the accuracy of the analysis marks were painted on the lips of the subjects and a head rest was used to minimize head movements.

With the aid of a projection device meeting with high demands on accuracy the x- and y-coordinates of arbitrary points on individual film frames were read by means of a cross-hair system. The numerical information obtained in this way was then processed by a PDP-7 digital computer for various computations (see below). Corrections for head rotations and movements were incorporated into this procedure which was found to make possible repeated estimations of lip and mandible positions that are well within plus-minus half a millimeter in most cases.

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Descriptive framework

If it is assumed that the lip contours when projected on a coronal plane can be represented by segments of power functions the projected area of either mouth segment is given by

$$A = \frac{b}{2} \int_{-\frac{b}{2}}^{\frac{b}{2}} a\left[1 - \left(\frac{2}{b}\right)^p \left|\frac{x}{b}\right|^p\right] dx = \frac{P}{p+1} \cdot ab \quad (1)$$

where $a$ is the position of the contour in the midsagittal plane and $b$ is the width of opening (Fig. I-B-1). The value of $p$ was established for a number of situations and turned out to be practically independent vowel and consonant category as well as time. For one talker it was found that, for a given height and width of mouth opening, the lip contours that always yielded areas equivalent to the observed ones were segments of third-degree power functions.

The set of labial parameters shown in Fig. I-B-2 includes

the vertical location of the upper lip ($a_u$)

" " of the mouth corner ($a_m$), and

" " of the lower lip ($a_l$) which are all defined along a sagittal plane rel. to the lower edge of the upper incisors;

the width of opening ($b$);

the horizontal location of the upper lip ($c_u$)

" " of the mouth corner ($c_m$)

" " of the lower lip ($c_l$) which are all defined along an anterior-posterior dimension parallel to the Frankfurt horizontal (indicated by the dotted line in Fig. I-B-2).

In the sagittal plane the contours are approximated by straight lines. The contour shapes associated with any given speech sound are thus segments of power functions and straight lines and are specified in terms of the above-mentioned parameters and the exponent $p$ which is treated as a constant. From this representation of labial shape acoustically relevant measures such as the cross-sectional area of the mouth-opening and the length of the lip section can be derived. When the mechanical constraints of the lips are better understood simplifications of the present inventory of parameters are to be expected.
Fig. I-B-1. Power function approximation of lip contour in coronal projection. The height, width, and area of mouth opening segment are denoted by $a$, $b$, and $A$, respectively.

$$y = a \left[ 1 - \left( \frac{2^p}{b} \right) |x|^p \right]$$

$$A = \frac{p}{p+1} \cdot ab$$
Fig. I-B-2. Definition of labial parameters.
Measure of labialization

A lip configuration can be said to be labialized if it deviates in some way from the neutral shape associated with relaxed lip musculature. Obviously this neutral shape varies with the position of the mandible. As a measure of labialization it is suggested that the difference between the actual position of the parameter and its jaw-dependent location be computed for each labial parameter and for each point in time during an utterance.

A computer program has been written that incorporates empirically established corrections for the jaw-dependence of labial parameters. For a given utterance the program processes the raw data on the mandible and the labial parameters obtained from the films, computes the associated jaw-dependent variations and the labialization difference curves. Fig. I-B-3 illustrates how the process of labialization represented in terms three such difference curves runs its course in relation to the acoustic events during the Swedish nonsense word [a'hoi].

Quantification of timing, rate, and extent of movement

In general the labial parameters change from one steady-state value to another in a fashion that rather closely resembles the response of a non-oscillatory second-order system to a step-function input. The time functions fitted to the articulatory transitions in Fig. I-B-3 were obtained from the convolution integral

\[ c(t) = \int_{0}^{t} g(\tau) \cdot (t-\tau)e^{-\alpha(t-\tau)}d\tau \]  

(2)

where

\[ g(t) = A_1u(t) + (A_2-A_1)u(t-t_1) \]  

(3)

The initiation of the transitional gesture occurs at a time \( t_1 \). The rate at which the time function changes is determined by the choice of impulse response and \( \alpha \). The extent of the movement is equal to \( (A_2-A_1) \), the difference between the two steady-states or targets involved.

Reference:

Fig. 1-B-3. Displacement of height and width of opening and the protrusion of mouth corner from neutral jaw-dependent positions in [a'hot]. Responses of second-order system (solid lines) to step-function input (dashed lines) have been fitted to the data.