MANDIBULAR MOVEMENTS AND SYLLABLES

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ABSTRACT

Jaw movements in phrases were studied optoelectronically (Selspot). The trajectories were constantly oscillating and quasi-regular. Most often, one oscillatory period corresponded to a syllable, with the dip in the vowel. This pattern was sustained also in high vowel contexts with oscillation amplitudes of only 1 mm. Integrated jaw oscillations were sometimes found before speech onset, and in silent pauses between phrases. These never-resting jaw movements constitute the basic syllabic speech structure. Cases of two syllables per mandibular period were also found. The conditions for such reductions are an urgent reseach issue.

INTRODUCTION

The syllable is a central but poorly understood phonetic entity. Evidently, it is highly important in both speech production and perception. Among other things, speech stress and rhythm patterns are closely connected to the syllabic structure.

A number of different phonetic correlates of the syllable have been proposed, both auditory and articulatory: sonority, loudness, degree of coarticulation, articulatory opening and closing, jaw movements [1, 2, 3]. However, no one-to-one, exceptionless correlate has been found. Nevertheless, the connections between speech syllabicity and these variables are far-reaching and significant.

Jaw movements are obviously closely connected with syllabic structure. These syllable-related movements are easy to observe with the naked eye. It is no coincidence that ventriloquists move the doll's jaw at a syllabic rate to give an impression of talk. Although it is possible to speak with a clenched jaw, it is highly unusual. Therefore, it is natural that hypotheses of mandibular movements as connected to syllabicity have been proposed long ago. Saussure's [2] proposal of closing movements (implosions) and opening ones (explosions) in connecting with syllabic boundaries is one example. Another, more elaborated hypothesis of the mandibular-syllabic connection was presented by Menzerath & de Lacerda [3] in the thirties. However, due to lack of technical possibilities at that time, the hypothesis could not be tested properly.

Today, technical resources exist for exploring the mandibular-syllabic connection. Strain-gauge and magnetic coil equipments, cineradiography, microbeam X-ray and optoelectronic filming have been used for tracking jaw movements [4, 5, 6]. Several studies have been reported since about 1980 of mandibular amplitudes and movements in relation to different sounds, stress, and tempo, e g [4, 5, 6]. However, the mandibular-syllabic connection has not been given much attention. The main aim of this paper is to give some fundamental, preliminary data on this issue.

Our main hypotheses are: (1) There is a far-reaching but not total correspondence between oscillatory jaw movement periods and syllables in speech. (2) The never-resting jaw movements constitute the basic syllabic speech structure.

METHOD AND MATERIAL

To elucidate the extent and nature of the mandibular-syllabic connection, the jaw movements have been analysed in natural phrases with the aid of optoelectronic filming (Selspot). This equipment consists of three basic units: light-emitting diodes, a position-sensitive detector located in two cameras, and a computer with a camera interface. For a closer description, see [7]. With this equipment, the three-dimensional spatial movements of one or more diodes can be analysed and displayed in calibrated curves and/or quantitative data, giving values of displacement amplitudes, velocities and velocity changes.

This study was based on systematic analysis of curves of mandibular movements in the vertical dimension only. The jaw movements were recorded at a sampling rate of 500 Hz by a single diode attached to the midline of the chin. Head movements were compensated for by a

reference system consisting of three diodes attached to a spectacle frame worn by the subject. This registration was supplemented with a simultaneous microphone recording of the acoustic signal. This signal was registered in synchrony with the movement curve as an LP filtered acoustic waveform. In this curve, the segmentation of sound segments of the utterances were made. The acoustic signal was also perceptually analysed as concerns the different informants' degree of speech reduction and tempo.

Two substudies, A and B, have been made. In study A, 12 dental students participated, eight women and four men, mean age 24 years, range 22-27 years. (This study has been published [8].) In study B, ten other subjects participated, four women and six men, mean age 31 years, range 23-49 years. Nine of these were also dental students. All subjects were native speakers of Swedish with normal hearing.

The material spoken consisted mainly of natural phrases in Swedish, well varied as concerns vowels, consonants, consonant clusters, and stresses. The material in study A consisted of *Mississippi*, [ˌmɪsɪˊsɪpɪ], *Pappa tappar kopparna*, [ˋpapa ˋtapa(r) ˋkɔpaɳa], "Daddy drops the cups", and *Prinsessan sätter potatis* [prɪnˋsesa(n) ˌsetə(r) pʊˋtɑ:tɪs], "The princess sets potatoes". In study B, the phrases were *Statsministerns sista tal måste läsas*, [ˋstasm(ɪ)ˌnɪstən(s) ˊsɪsta ˊtɑ:l mɔstə ˋlɛ:sas], "The prime minister's last speech has to be read", and *Cecilia tjatade att hon måste kila bort och kika på Sassas nya kjol*, [səˊsi:lɪa ˋɕɑ:ta (a)t (h)ʊ(n) mɔstə ˌɕi:la ˊbɔʈ ɔ ˋɕi:ka p(ɔ) ˋsasas ˋny:ja ˊɕu:l], "Cecilia kept saying that she had to run away and look at Sassa's new skirt". (The diacritics ˊ and ˋ denote main stressed syllables, associated with Swedish tonal accent I and II, respectively. The parentheses surround segments that are often reduced.)

In study A, the three items were spoken one at a time. Each item was uttered five times by all 12 subjects. In study B, the two phrases were uttered with a very short pause between them. Each such sequence was uttered nine times by all 10 subjects. All informants spoke with a normal loudness and tempo, resulting in numerous expected reductions of consonant clusters and unstressed vowels.

RESULTS

The 22 subjects generally had similar mandibular movement patterns, albeit with some individual differences. Fig 1 shows a representative curve from one of the subjects. Several features found in all or most of the informants' curves will now be described.

(1) The jaw was constantly moving during the utterances. A permanent oscillating pattern with peaks and valleys characterized all utterances by all speakers. The vertical movement amplitudes were on average 5 mm and maximally 8-12 mm. A mandibular period had a mean duration of about 0.230 sec.

(2) The speed of the mandibular lowerings and raisings tended to be constant, resulting in symmetric peaks and dips in the curves.

(3) The mandibular movement periodicity showed a strong connection with the syllabic structure. Thus, there was a strong tendency for one dip to occur in each vowel and one peak in the consonant(s) in between. Generally, there was no cases of a dip connected with a single consonant or a peak with a single vowel.

However, in less than 10% in the whole material, a VCV sequence corresponded to a single curve valley. This dip was typically deeper and longer than the average. In most cases, this C was [ɳ] or [n] in phrase final VCV in *kopparna* (substudy A), and [l] in various positions in the two phrases in substudy B. The durations of these consonantal segments, measured in the waveforms, were normal.

In addition, there were a few cases of two small curve dips in a single vowel. These were only found in some speakers in the stressed, long [ɑ:] in *tal* and *tjata*.

(4) In several sequencies with high vowels, mandibular oscillation amplitude was very small, only 1-2 mm, cf Fig 2. This was found for several speakers in *Mississippi*, *Prinsessan sätter potatis*,

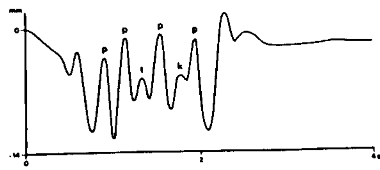

Figure 1. Mandibular movement curve of subject A reading Pappa tappar kopparna.

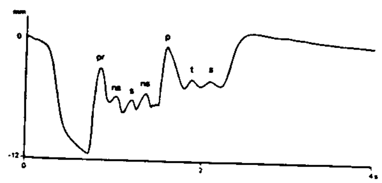

Figure 2. Mandibular movement curve of subject H reading Prinsessan sätter potatis.

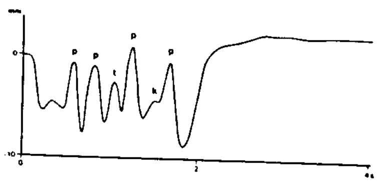

Figure 3. Mandibular movement curve of subject D reading Pappa tappar kopparna.

and in the fat type part of ***Statsministerns sista tal måste läsas***. Thus, the permanent jaw oscillation, correlated with the syllabic structure, was sustained on a very small amplitude scale here.

(5) Most often, the mandibular movement pattern immediately before speech onset and in the pause between the two consecutive phrases was different from the undulating speech mode, cf Fig 2. However, in some cases an integrated oscillation of the speech type was found also in these speech-outside positions. See Fig 1 and 3. Thus, sometimes the oscillating jaw movement was started one or two periods before the speech onset and was also sustained during short silent pauses.

DISCUSSION

Method

The Selspot diode placing on the chin led to an artifactual deviation in labial consonant jaw amplitudes. Due to tissue stretching, our amplitude values were too high in these sounds, higher than in dental consonants. According to other studies with no such artifact, e g [6], alveolar/dental consonants have somewhat higher mandibular positions than labial ones. To avoid this problem, we have tested diode placings on the lower front teeth. This position is however also unsuitable, since the diode emitted light is often absorbed by the lower lip. In future investigations, we shall therefore place the diode on a small, rigid, bent metal stalk glued to a lower teeth.

In spite of this, our present data are valid for an analysis of several aspects of the close mandibular-syllabic relation.

The mandibular-syllabic connection

Obviously, speech is characterized by a quasi-regular, continuous jaw oscillation. No mandibular steady state was seen in 360 phrases uttered by 22 speakers. The movements also tended to be symmetric. This is unlike e g the tongue, which moves in a more irregular way, with intermittent steady states [9].

Furthermore, the permanent mandibular undulating pattern had a very close correspondence with the syllabic pattern of the utterances. The jaw opening movements were connected with the vowels and the closing movements with the consonants.

This undulating pattern was seen also in several sequences with high vowels, where oscillation amplitudes were only 1-2 mm, cf Fig 2. This is highly significant. The production of the individual consonants and vowels in such sequences do not demand such mandibular precision. Obviously, the very small movements have another function. Our hypothesis is that the never-resting, oscillating mandibular movements constitute the basic syllabic structure of speech.

Other articulators, e g the tongue, sometimes display steady states [9]. Therefore, it was a priori not unreasonable to suppose that the lower jaw should be kept still in a sequence of sounds like *Mississippi*, where [s] and [i] have similar, close jaw positions.

According to our hypothesis, the main reason for these permanent, oscillating movements of the lower jaw is its basic role as prime mover in connection with syllabic structure. It is however not a necessary mover. The syllabic structuring of speech is of course lead by centers in the brain. Other articulatory tools can take the place of the jaw. But this is unusual. It is also true that the mandibular-syllabic connection is not completely one-to-one. But for about 90% of over 4000 syllables in our material, there was a one-to-one connection with mandibular periods.

Almost all cases of exceptions from this general one-to-one correspondence consisted of one opening-closing mandibular movement during two consecutive syllables. (No cases of three syllables in one mandibular period was found.) The duration of the consonant C in the bisyllabic mandibular period - VCV - was normal. Since the composition of the phrases used was restricted, definite conclusions cannot at this stage be drawn about the factors that condition these reductions. However, in almost all cases, the C was a front tongue sonorant - [n, ɳ] or [l], and one or both of the Vs an open vowel - [a] or [ɛ:] - with very low jaw position.

Obviusly, an urgent research task is to systematically map the conditions for these reductions. The aim of this research is to construct a model of speech syllabicity. This model must also integrate some other data. One of these is some few cases in our material of two mandibular oscillation periods within one syllable. These cases were only found in [ɑ:] in a stressed syllable. Since [ɑ:] has the longest inherent duration universally, and also in Swedish, this is more natural than if the double dip had been found in other vowels.

This double-period mandibular trajectory within a long vowel gives the impression of the lower jaw as an oscillator, moving within some frequency limits, conditioned by its size and shape. Most often, the syllable durations fit this periodicity. This oscillator concept is not new in speech articulation research [10].

Also some other of our data support the hypothesis that the mandibulum is an articulatory oscillator. They also indicate that it may be the prime mover, in accord with which the tongue and other articulators move. These data are the cases of integrated pre-phrasal jaw oscillation. Some of these cases consist of two periods, with either equal amplitudes (Fig 3) or a very small first dip (Fig 1), giving the impression of an oscillator softly starting. Also a number of cases of permanent, integrated mandibular oscillations within silent pauses between phrases support this view.

Syllables arise in baby babble around the age of six months, making it more speechlike. The cause of this is the appearance of regular lower jaw opening and closing movements [11]. In this speechlike babble, mandibular movements seem always to have a one-to-one connection with the syllables [11]. In grown-ups - and also in children aged 5-7 years [12] - this one-to-one connection is somewhat modified by some reductions mainly, but basically the same.

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