HOW AND WHY DO THE TONGUE GESTURES OF [t], [d], [l], [n], [s], AND [r] DIFFER?

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ABSTRACT

The detailed front tongue gestures of [tdlnsr] differ intralingually, according to an interlingually widespread pattern. This pattern reflects general, sound-specific production conditions, such as: [s] demands a high mandibular position, a laminar groove, and an air-jet hitting the front incisors; [r] demands a well-balanced interplay of aerodynamic and organic factors, including absence of laminar tension; [l] has a transverse tongue compression and a lower mandibular position.

Swedish EPG data on [l] and other front coronals are presented and discussed partly in relation to the three-dimensional physiological tongue models of Stone and Wilhelms-Tricarico. Such models need empiric data like ours to develop. Also, detailed data will eventually be explained by such models.

We hypothesise: the [l] tendency to be apical more often than other coronals is due to its low mandibular position; this low position is due to its vertical tongue thickening and a strategy to avoid velarisation.

1. INTRODUCTION

1.1. Coronals in a global perspective

Front tongue consonant phonemes articulated against the upper incisors and/or the alveolar crest are outstanding in a global perspective. First, the coronal gesture is generally combined with more manners than the labial, dorsal, pharyngeal and glottal gestures taken together. E. g., front tongue /l/ and /r/ are mostly the only liquid phonemes in languages [12]. Also, the sibilantic groove constriction is coronal, with no or very few exceptions; since most affricates are sibilantic, also this consonantal class is prodominantly coronal [6].

The large number of coronal phonemes in the languages of the world is caused not only by the high compatibility of the coronal gesture with different manners. Also one and the same manner is often used in two and sometimes more places along the short sagittal range streching from the upper incisors mainly about 15 mm back to the postalveolar region. In no other part of the vocal tract is such a short range equally exploited phonologically. This is due to several factors: the motor versatility of the front tongue; turbulence promoting conditions in the dentialveolar region; the fact that for obstruents, the front cavity, decisive for resonance shaping, is small, implying that also small absolute changes lead to great changes in relative size and resonatory effect [6]. In several cases, these size changes are due not only to sagittal length changes but also to the connection/disconnection of the sublingual cavity, which accompanies front tongue sagittal movements in the alveolar region.

Due to these conditions, a large proportion of the consonant phonemes of most of the world's languages are coronal. This is reflected in the proportion of coronal sounds among the most common phonemes pooled over a large number of languages. Thus, Maddieson [12] found that 10 of the 20 most common consonants were coronal.

An overview of several studies of coronals is given in Keating [4], together with a penetrating discussion of the terminology and definitions in this area. Also Ladefoged & Maddieson [5] treat this area closely.

1.2. The detailed gestures of especially front coronals

The front coronal sounds [t d n l s r] of a certain language are often described as sharing the same articulation place or gesture. From a phonological point of view this rough generalization may often be justified. However, for the purpose of phonetic model work and pedagogic or odontologic applications, a closer description is needed. As shown by Dart [2] for a large number of French and American English speakers, there are differences. First, the interindividual variation was great. The same coronal sound in both languages were produced apically by some and laminally by others. For /t d n/ she found a statistical language difference: In French, more speakers had a laminal and dental gesture, but in English the apical and alveolar pronunciation was more common. However, in both languages laminal /s/ was more common, whereas /l/ tended strongly to be apical. According to [2], this may be a universal tendency, caused by specific production conditions for each constriction type, making the production easier for most speakers. One of the goals of this article is to focus on those conditions and to contribute to the exploration of this important area. This is done by presenting detailed EPG data on some Swedish coronals, and by trying to relate some of these data to anatomical and physiological factors that restrain and influence tongue muscle acticity patterns. Some such factors are formalised in the three-dimensional physiological articulatory models of Stone [14] and Wilhelms-Tricarico [16].

A couple of specific production conditions will be exemplified: Especially [s] and trilled [r] have conditions, well-known in general terms, that necessitate highly specific, very precise gestures: [s] demands a laminar groove and an air jet hitting the front incisors, and a small interincisor distance [6, 8]; in trilled [r], the front tongue vibrations, caused by the interplay of aerodynamic and organic factors, demand a highly specific front tongue shape and position, and absence of tension.

The discussion in the last two paragraphs concerns front coronal sounds. However, the hypothesis that sounds that share roughly the same articulatory gesture nevertheless tend to differ in gestural details, caused by general production conditions for each specific articulatory manner, is certainly valid also for all other sounds, not least posterior coronals such as retroflex sounds and [ʃ].

2. SWEDISH CORONALS

The Swedish consonant system is generally considered to consist of the following phonemes: /p t k; b d g; f s ç ɧ h; v j; l r; m n ŋ/. Six of these 18 sounds are exclusively coronal: /t d s ç l n/. /r/ is coronally produced in Central but not South Swedish. /ɧ/ has several allophones, one of which [ʃ] is a coronal. [ʃ] is very similar to and often identical with English [ʃ]. Despite this, it is usually symbolysed by [ʂ].

Both /ç/ and [ʃ] are postalveolar coronal sibilants, with very similar groove position, width and length [8]. Their main difference is the front cavity size. In [ʃ] this is larger, due to lip rounding - as contrasted to spreading in /ç/ - and also to a larger sublingual cavity [6, 8]. In consequence, [ʃ] has lower energy distribution and a darker auditory shade than /ç/ [6]. Also, /ç/ is palatalised.

Traditionally, Swedish /t d l n/ are roughly described as dental. Compared to English corresponding sounds, they are generally more front. Also /s/ is sometimes classified as dental, although it is generally prealveolar [8] and thus similar to e. g. English /s/. Swedish coronal /r/ is however classified as alveolar. This sound varies greatly: trilled, fricative, and approximantic; often it is totally reduced in weak positions.

Thus, 8 out of the 18 Swedish consonant phonemes are coronal. The proportion of front tongue sounds will be higher - 12 out of 22 - if also a postalveolar group of Swedish consonants is included, which are mostly regarded as allophones of /r/ plus one of /t d l n s/. Most Swedes systematically produce a postalveolar or prepalatal coronal constriction not only for /ç/ and the /ɧ/-allophone [ʃ] but also for allophonic variants of /t d l n s/ when following /r/, as in *port, hård, Karl, törne, fars* - "door, hard, thorn, Charles, farce". /r/ is not realized as a separate segment in these cases.

The (hyper) gesture of those allophones is often classified as retroflex, but also as apicoalveolar, or supradental. The usual notations are [ʈ ɖ ɳ ɭ ʂ] respectively. However, the tounge tip position is probably very often not bent backwards (retroflex) but only lifted upwards. In accordance with [5], the most adequate notation for these sounds would therefore be the basic signs [t d l n s] with a dot below. The /r+s/ allophone denoted [ʂ] and the /ɧ/ allophone [ʃ] are identical. However, [ʃ] varies as concerns the detailed front tongue shape and position, and degree of lip rounding [6, 10].

Thus, detailed investigations of the tongue gestures in coronal sounds remain to be made, in Swedish as well as in other languages. One goal of this article is to contribute to this mapping with EPG data for Swedish /t/, /d/, and /l/.

The description above of Swedish sounds concerns hyper style speech only. Traditionally, phonetics has focused on this level, so there is little information on hypo production. However, [11] treats the hypo level of Swedish /s/, /ç/, and [ʃ].

3. METHOD

3.1 Material

Ten Swedish speakers participated, 6 males and 4 females, age range 24-50 years. Six spoke Central and 4 South Swedish varieties. One male and 3 females were South Swedish.

Lists of nonsense words were recorded acoustically and with EPG (Reading type) simultaneously. The subjects, who hade participated before in EPG registrations, wore dummy palates, similar to the EPG ones, for several hours before the registration. The words were read in randomized order. The part of the material used in this study was as follows: 1) Ten tokens of each combination of ˈsV:la, where V: = /i: e: y: ø: ɑ: u:/. 2) Four tokens of each combination of ˈ$V{:}_1$,$CV{:}_2$, where C = /t d l r/ and in each token $V{:}_1 = V{:}_2$ and V: = /i: ɑ: u:/.

3.2. Analysis

In the Reading EPG palates [3], 62 electrodes are placed in a regular pattern of 8x8 rows. The electrode diameter is 1.4 mm. All transverse electrode rows are approximately straight as projected on a horizontal plane, and consist of 8 electrodes except for the frontmost one, which has only 6 electrodes due to the restricted space close to the teeth. In this first row, at least one electrode covers an incisive. Tongue gestures contacting this row may therefore be classed as dental. The three following rows cover the alveolar region, going back about 15 mm from the teeth. Tongue contacts with those rows are alveolar. Prealveolar concerns row two, postalveolar row three and four. For these four frontmost rows, the interelectrode distances are about 4 mm, both sagittally and transversely. In the palatal region further back, interelectrode distances are greater, especially sagitally. The backmost electrode row is close to the boundary between the hard and soft palate.

Each EPG registration frame shows the tongue-palate contact avery 10 ms, with touched and untouched electrodes represented differerently. When only one transverse row in the alveolar region is touched by the front tongue, the sagittal constriction length may be up to maximally about 6 mm. Two touched rows corresponds to about 5-9 mm, 3 touched rows to about 7-15. When all four front rows are touched, the length is at least about 11 mm.

The apex tip margin has a thickness of maximally about 6 mm. This means that a contact encompassing three or more transverse rows must be laminal, not apical. Contacts of one och two rows are often apical but not always: at the alveolar crest maximal curvature, a laminal gesture may contact fewer than three rows [2].

4. RESULTS AND DISCUSSION

4.1. /t/ and /d/

See Table 1. /t/ was pronounced dentally by all 10 subjects. In contrast, /d/ was dental in 5, alveolar in 2 and mixed dental/alveolar in 3 subjects (B,C,E). Speaker B and C had dental /d/ in /i:/ context and alveolar /d/ in /ɑ:, u:/ context. E had alveolar /d/ in /ɑ:/ context only. All 5 subjects with unmixed dental /d/ were Central Swedish speakers. They were also male, whereas the sixth Central Swedish speaker (E), a female, had a mixed pattern. All 4 South Swedish speakers (A-D) had an alveolar or mixed /d/

One central Swedish speaker (F) had equally large tongue contact areas in /t/ and /d/. In 9 speakers, the /t/ area was conspicuously larger. Their average (sagittal) constriction length in /t/ was 3.3 rows, range 2.6-4.0. In contrast, their average /d/ constriction length was 2.3 rows, range 1.6-3,0. Since /t/ had generally tongue contact in row 1, it was obviously both dental and alveolar, and the contact was also laminal and probably apical.

Table 1. EPG data on lingual contact areas of Swedish /t/, /d/, and /l/ for 10 subjects (A-K); f = female, m = male. A-D are South Swedish and E-K Central Swedish speakers. Articulatory place symbols: dent = dental, alv = alveolar, d/a = mixed dental and alveolar. The areas compared are the coronal contact areas in the dentialveolar region. The measure of constriction depth is the average number of touched dentialveolar electrode rows (n = 12); the value 2 ≈ 5-9 mm, 3 ≈ 7-15 mm, and 4 ≥ about 11 mm.

Subject	A m	B f	C f	D f	E f	F m	G m	H m	J m	K m	Average
/t/ place	dent	dent	dent	dent	dent	dent	dent	dent	dent	dent	
/d/ place	alv	d/a	d/a	alv	d/a	dent	dent	dent	dent	dent	
/l/ place	alv	dent	d/a	d/a	d/a	dent	d/a	alv	dent	d/a	
largest area /t-d/	/t/	/t/	/t/	/t/	/t/	=	/t/	/t/	/t/	/t/	
largest area /d-l/	=	/l/	=	/l/	/l/	=	/d/	=	/l/	/d/	
/t/ constr depth	4.0	2.8	3.1	2.6	3.0	2.1	4.0	2.8	3.8	4.0	3.2
/d/ constr depth	2.1	2.1	2.0	1.6	2.3	2.0	3.0	2.0	2.7	3.0	2.3
/l/ constr depth	2.0	2.6	2.1	1.9	2.7	2.0	2.3	2.1	3.4	2.3	2.3

Thus, Swedish /t/ appears to be not just apical and dental, as it is traditionally classified, but apicolaminal and dentialveolar. This is natural, since when the tongue tip contacts the upper incisors, the blade will generally make contact with the fairly horizontal prealveolar region [2]. Also Swedish /d/ is at least partly made in this way.

The reasonable explanation of the great tongue area difference between /t/ and /d/ is that /t/ is fortis and /d/ lenis.

4.2. /d/ and /l/

/l/ was dental in 3, alveolar in 2 and mixed dental/alveolar in 5 subjects (C, D, E, G, K) (Table 1). Speaker C, G, and K had dental /l/ in /i:/ context and alveolar /l/ in /ɑ:, u:/ context. In D and E, /l/ was dental mainly in /ɑ:/ context.

In cases of mixed dental/alveolar pronunciation of /d/ or /l/, the dental contact in /i:/ context was the most common pattern. This pattern was always seen for mixed /d/. This result is not unexpected, since the /i:/ gesture brings the tongue body closer to the upper incisives. Also /u:/ context gave dental /d/ in one speaker with mixed pattern, but there were no cases of dental mixed /d/ in /ɑ:/ context. In contrast, two speakers with mixed /l/ had a dental gesture mainly in /ɑ:/ context. Since the material is small, no safe conclusions can be drawn now. However, since /l/ is produced with a lower mandibular position than other consonants [7] and different tongue muscle activity than /d/, this difference ought to be studied in a larger study. Also Dart [2] found a somewhat different detailed production pattern for /l/ compared to /d/ (and /t n/) in English and French.

Notice that the /d/ and /l/ production patterns as concerns the dental/alveolar distinction were not parallell in 5 of the speakers (Table 1). B had mixed dental/alveolar /d/ but dental /l/. D had alveolar /d/ but mixed /l/. G and K had dental /d/ but mixed /l/. H had dental /d/ but alveolar /l/. In 5 speakers, /d/ and /l/ patterns were parallell: A (alveolar), C and E (mixed), F and J (dental).

On the average, the recorded dentialveolar /l/ tongue contact area was smaller than for /t/ but similar to /d/. Four speakers had equal /l/ and /d/ areas, 2 (G, K) had smaller and 4 (B, D, E, J) had larger /l/ areas. The contrast to /t/ is in line with the Dart [2] finding that English and French /l/ tends strongly to be apical and thus to have a small contact area.

4.3. Two /l/ types and other lateral issues

The total /l/ contact areas, including also the palatal region, were of two different kinds. In 9 speakers, the area had a horseshoe shape. Mostly, the side contact areas (wings) were extended far back on both sides. Five speakers (B, C, D, E, H) tended to have a symmetrical pattern, with wings extended to the 7th row, which means that the wings were more than 30 mm long and had their ends no farther than 10 mm from the velum. Four speakers (A, F, G, K) tended to have an asymmetric pattern, with one wing extending to the backmost row and the other to the 7th. On the more open side, the wing had its end no farther than 10 mm from the velum. The other wing extended over the whole palate, and we have no information about its back end, which may be somewhere on the velum. The open side was on the left in 2 and on the right in 2 cases.

Only one speaker (J) had another kind of tongue contact area, characterized by no or very short wings. This pattern was dominating in J, but he had also cases with somewhat longer wings. His front contact area was dentialveolar, with 3 or 4 rows covered. This contact was sagittally clearly wider than in all other subjects, cf Table 1. The auditive impression of J:s /l/ was not deviating.

Several phonetic texts - e. g. [5, 13] - give the impression or state explicitly that the wingless /l/ is common or most generally used. Our result indicates that the horseshoe shaped type may be more general.

In our material [l] is probably apical - as its constriction depth is around 2 EPG rows, cf Table 1, which corresponds to about 5-9 mm. In Dart's [2] larger English and French material, the tendency was strong that [l] was apical rather than laminal, irrespective of the detailed gesture of other front coronals. Therefore, we hypothesise that globally, [l] tends to be apical rather than laminal, also in languages where other coronals do not share this detailed gesture. The explanation of this is that the jaw position in [l] tends to be comparatively low [7], and consequently also the front tongue. Since the distance between the front tongue and the oral ceiling is thus relatively large, a coronal constriction is connected with a greater lifting of the front tongue and thus with an apical contact.

An opposite hypothesis is proposed for [s]: Since this sound demands a small interincisor distance, its jaw position is high, and also its tongue body position. Consequently, the lifting of the front tongue will be small, causing the blade to make the contact.This hypothesis is supported by large proportions of laminal as contrasted to apical [s] gestures in British English [1] and American English and French [2].

Another general hypothesis about [l], which comes to mind at a close look at its specific gesture conditions - and which may get a formalised explanation in future models - concerns the fact that [l] tends to be velarised (or possibly faryngalised) in many languages much more than other front coronals do. One important underlying general phonetic cause of this tendency seems to be the fact that the activity of the internal, transverse lingual muscles aiming to create lateral opening(s) also tends to lengthen the tongue. This is easily felt by proprioceptive feedback. Since the mass of the tongue is essentially constant and the position of the front tongue can not vary to a great extent, it is natural that an expansion of posterior parts of the tongue will arise in [l].

The transversus muscle activity also tends to make the tongue vertically thicker. This fact is also easily felt.

Thus, [l] has three characteristics: the vertical thickness, the tendency to be velarised, found in several languages of the world, and a comparatively low mandibular position, which is found in Swedish [7] and many other languages. No other front coronal sound shows these features. A natural question is whether there is a connection between them. We hypothesise that this is the case for the mandibular position and the velarisation tendency, for the following reason. The perceptual effect of a sufficient degree of velarisation or faryngalisation is noticeable: a darker sound quality. In some languages, this quality is standard [l] pronunciation and no activity is made to avoid this easily arising [l] feature. In other languages, this quality is not accepted. To avoid it, a lower mandibular position may be a common strategy. This will lower the whole tongue body and lead to a a wider cross section area in the velar or upper faryngeal region.

This hypothesis may be strengthened or refuted by studying the correlation in a number of languages between mandibular position and the presence of velarisation in [l].

4.4. Physiological models and detailed coronal gesture data

During the last decade, articulatory tongue models have been developed, especially by Stone [14] and Wilhelms-Tricarico [16]. Being three-dimensional, they are more realistic than older ones, that had only two dimensions. This is a very important change for a realistic modeling of lingual shape as associated with varying activity degree in various tongue muscles.

Stone has made important contributions to the modeling work for coronals, based on ultrasound, MRI, EPG, and x-ray microbeam analyses. Thus, she has shown [14, 15] that the transverse shape - along a concave-convex dimension - of the dorsum varies not only between e.g. [s] and [l], but also often between the front and back part of the tongue in one and the same sound. She also stresses the great importance of the front lingual contact with the oral ceiling as a support for the tongue muscle work in speech. Her physiological tongue model divides the tongue in several sections both in the sagittal and transverse planes. In a non-formalised way she discusses the effect of various tongue muscles on these lingual sections and thus on the tongue shape.

The computerised, more formalised tongue model of Wilhelms-Tricarico [16] contains 42 three-dimensional elements, together making up the whole lingual mass. The shape of each element can be changed primarily by the activity of one or more muscles with fibers within the element. The effect of varying the degree of activity in various tongue muscles has been computer simulated and shown in three-dimensional tongue figures, that often show good similarity to empirically mapped tongue shapes.

The project of modeling the articulating tongue is an enormously difficult task. The tongue is a highly complicated organ with several degrees of freedom. At least 12 pairs of muscles make up its main body and tip. Partially, they are interwoven. Many more than 42 model elements are therefore needed [16]. Also several other simplifications are made in the present models and will probably have to be made also in those that will appear during the next decades. In the future, one important function of tongue models ought to be to explain at least part of the empirical detailed data on e.g. coronal gestures like those presented in this article. The relation between models and data is however reciprocal: The further development of realistic articulatory models demands detailed production data like ours.

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