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ASYMMETRY IN THE CZECH ALVEOLAR STOPS: AN EPG STUDY

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ABSTRACT

Previous informal observations suggested a more anterior place of articulation in [t] than in [d] or [n] in Czech, a rather rare phenomenon from the crosslinguistic perspective. The objective of this study is to verify the existence of this asymmetry objectively using electropalatography, and also to compare linguopalatal contact across vocalic contexts. The results show that, although speakers manifest slightly differing tendencies, [t] is indeed produced with a more anterior articulation than [d] in six out of the seven speakers analyzed. Moreover, [t] appears to be more resistant to coarticulation, which is in agreement with studies suggesting greater coarticulation resistance in voiceless and laminal sounds than in voiced and apical sounds like [d].

Key words: alveolar stops, electropalatography, articulation, coarticulation, Czech

1. Introduction

The speech sounds [t] and [d] are typically described as alveolar stops, and there is general consensus in phonetic literature that they share the same place of articulation. In more detailed comparative accounts, the alveolar place is frequently collapsed together with the dental place of articulation (e.g., Maddieson, 1984: 31), also because it is quite uncommon for dental and alveolar plosives to be contrastive within one language. In fact, the UPSID database contains only six languages in which all four phonemes, /t/–/d/ and /t̪/–/d̪/, are present. It appears to be even rarer for a language to have one *t–d* pair in which the articulation places would differ: Maddieson (1984) mentions only two languages where an asymmetry within the voicing pair is explicitly stated and does not involve any other difference like prenasalization. Sundanese is described as having a dental /t̪/ and an alveolar /d/, while Kunimaipa has a dental /d̪/ and a /t/ which is classified as "dental/alveolar" (Maddieson, 1984).

It appears that the *t–d* pair in the Czech language (Czech is not included in Maddieson's UPSID database) also manifests an asymmetry of this kind: both informal observations and the scarce empirical descriptions indicate distinctive places of articulation of /t/ and /d/. Perhaps most notably, Antonín Frinta – one of the earliest Czech phoneticians – points out that the Czech [t] is a dental sound, while [d] is alveolar (Frinta, 1909: 124). The difference therefore seems to be a stable characteristic of the Czech sound system. Frinta based this observation on his own pronunciation and conceded that the contrast may be smaller in other speakers; he believes, however, that [t] is always produced as more anterior than [d]. Hála (1962: 224) defines the Czech [t] as denti-alveolar and [d] as alveolar, but he believes the difference to be insignificant, related merely to differences in the force of articulation. Indeed, his palatograms indicate only a very small difference in the place of articulation of [t] and [d]. In their acoustic description of Czech speechsounds, Borovičková and Maláč (1967: 47) also suggest a different articulation of the consonants but, similarly to Hála, merely invoke a different articulation energy, adding that the extent of the difference between [t] and [d] does not seem to be any greater than between the other cognates. Other sources do not comment on the possibly different articulation place of [t] and [d] at all. The main aim of this paper therefore is to shed more light on the articulation place of [t] and [d] in Czech.

The place of articulation of lingual sounds can be investigated using electropalatography (EPG), a method which detects contact between the tongue and an artificial palate. The artificial palate, custom-produced for every speaker, is fitted with electrodes which detect the tongue–palate contact in a binary manner. Currently most frequently used is the EPG3 system produced in Reading, England, with 62 electrodes placed along clearly defined anatomical landmarks (Wrench, 2006). The rows of electrodes correspond to individual places of articulation, as shown in Figure 1.

It has been discovered that voicing cognates such as *t–d* manifest tiny but systematic differences in tongue–palate contact, even in languages in which the members of the *t–d* pair do share the same place of articulation. These differences are caused by the aerodynamics of the distinction between fortis (strongly articulated, tense) and lenis (weakly articulated, lax) consonants. Initially, there were two contradictory hypotheses regarding

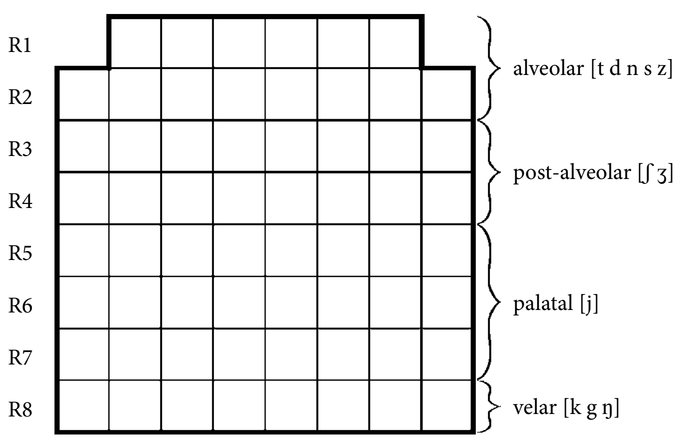

Figure 1. The EPG3 artificial palate. The correspondence to places of articulation, along with example speechsounds, are also indicated.

the effect of tenseness on the linguopalatal contact (see Skarnitzl, 2011: 96ff. for a more detailed discussion). First, the higher force of articulation in voiceless (fortis) plosives would result in a stronger contact between the tongue and the palate, while the lower force of articulation in voiced (lenis) plosives, along with mechanisms for expanding the vocal tract to accommodate the continuation of voicing (e.g., Westbury, 1983), would lead to a weaker contact. On the other hand, the second hypothesis states that the higher intraoral pressure in voiceless obstruents would "push" the tongue away from the palate, resulting in a weaker contact than in voiced obstruents in which the lax tongue could "spread around". Most EPG analyses support this second hypothesis: linguopalatal contact appears to be greater in lenis than in fortis obstruents (Dagenais et al., 1994; McLeod et al., 2006; Skarnitzl, 2011).

It must be pointed out, however, that the differences caused merely by the fortis–lenis distinction are typically of such small magnitudes that speakers do not feel their articulation of voiceless–voiced cognates as being different, certainly not in terms of the place of articulation. What speakers describe as the different force of articulation is, according to Malécot (1969: 1591f.), "primarily a synesthetic response to intra-buccal air pressure impulse". The situation in Czech thus appears to extend beyond this universal effect of the fortis–lenis distinction: informal queries indicate that Czech speakers clearly feel a different place of articulation in [t] and [d].

In this paper, we will use electropalatography to examine the place of articulation of [t] and [d] in Czech; the articulation place of the two plosives will also be compared with that of the third alveolar stop, the nasal [n]. The secondary objective of this study is to analyze the effect of the surrounding vowels on the linguopalatal contact in [t] and [d], especially in terms of its variability.

2. Method

Recordings of seven native Czech speakers (four females, three males) were obtained at the Institute of Phonetics in Prague. All subjects were employees or students at the Institute of Phonetics (the author is one of the speakers), they reported having normal hearing and no history of speech or neuro-motor defects. The EPG3 system was used to record dynamic linguopalatal contact, with one frame obtained every 10 ms. The acoustic signal was recorded as well, synchronized with the EPG signal, in order to facilitate the identification of target linguopalatal patterns. The speakers could not see the EPG display on the screen during data acquisition.

It is well known that speakers need to adapt to speaking with the artificial palate, and it has been reported that some speakers may never adapt completely (McAuliffe et al., 2008). That is why we followed general recommendations and recorded the speakers only after they had been speaking with the artificial palate for at least 30 minutes (Hardcastle and Gibbon, 1997).

EPG patterns were processed in ArticAssist (Wrench, 2006), the software tool provided with the EPG3 system. The points corresponding to the onset and offset of the closure for /t/ and /d/ were identified using the waveform and spectrogram. Since the raw EPG data consists in a 62-value vector in every frame, the analysis is quite complex in this form. That is why, although schematic displays making use of the entire palate or its subsection may be illustrative, several data reduction techniques have been proposed (see Gibbon and Nicolaidis, 1999 for a review) which allow for quantification and statistical comparison of EPG patterns. Those suitable for our analysis will be described in section 3.

The speakers were asked to read target words embedded in a carrier phrase *Řekni _____ ještě jednou* (*Say _____ once again*). The words, listed in Table 1, were selected so that the target consonant – /t/, /d/ or /n/ – is located in the onset of the second syllable and is flanked by two identical vowels.

Table 1. List of target words used in the experiment.

Flanking vowels	[t]	[d]	[n]
[ɪ]	itinerář (*itinerary*)	idylický (*idyllic*)	iniciální (*initial*)
[ɛ]	jetel (*clover*)	jeden (*one*)	Jeneč (*place name*)
[a]	vata (*cotton wool*)	vada (*flaw*)	vana (*bathtub*)
[o]	potomek (*descendant*)	podomek (*houseman*)	ponožka (*sock*)
[u]	putuje (*roam*-3RD-SG)	buduje (*build*-3RD-SG)	vsunuje (*insert*-3RD-SG)

Each target word, in the carrier phrase, was repeated three times by each speaker. In total, the following analysis will therefore be based on 45 items (15 per speechsound) from each speaker.

3. Results and discussion

3.1 The place of articulation of Czech [t], [d] and [n]

In order to determine the place of articulation of [t], [d] and [n], we identified the frame with the greatest amount of contact during the closure phase. As it is well known that, in comparison with acoustic analyses of speech, articulatory patterns tend to be much more variable across speakers (e.g., Maeda, 1991), the EPG data for our seven speakers will mostly be presented separately; collapsing them together may conceal interesting tendencies.

Figure 2 presents composite EPG displays of [t], [d] and [n] for our seven speakers. Only the first five rows of the palate are shown; the last three rows showed only random lateral contact and did not contribute any interesting information to the present analysis. Already this schematic display reveals illustrative differences between the target speechsounds. In accordance with Hála's (1962) description, the voiceless [t] appears to be a denti-alveolar speechsound in most speakers since only the first row is consistently contacted. Speaker M1 has a slightly more systematic contact in the second row, so that his [t] may be considered as denti-alveolar or alveolar. Only speaker M3's pronunciation of [t] deviates significantly from this description: the tongue–palate contact in [t] extends well into the postalveolar zone.

More importantly, the linguopalatal contact in voiced [d] seems to pattern differently from [t] in all speakers except for F4. Her realization of [d] is alveolar – which would correspond to Hála's description – while all the other speakers manifest considerable degrees of contact in the third or even fourth row, placing their [d] between the alveolar and postalveolar place of articulation. Speaker M3 again deviates from this general pattern in that his pronunciation tends towards the postalveolar place even more. In all, the

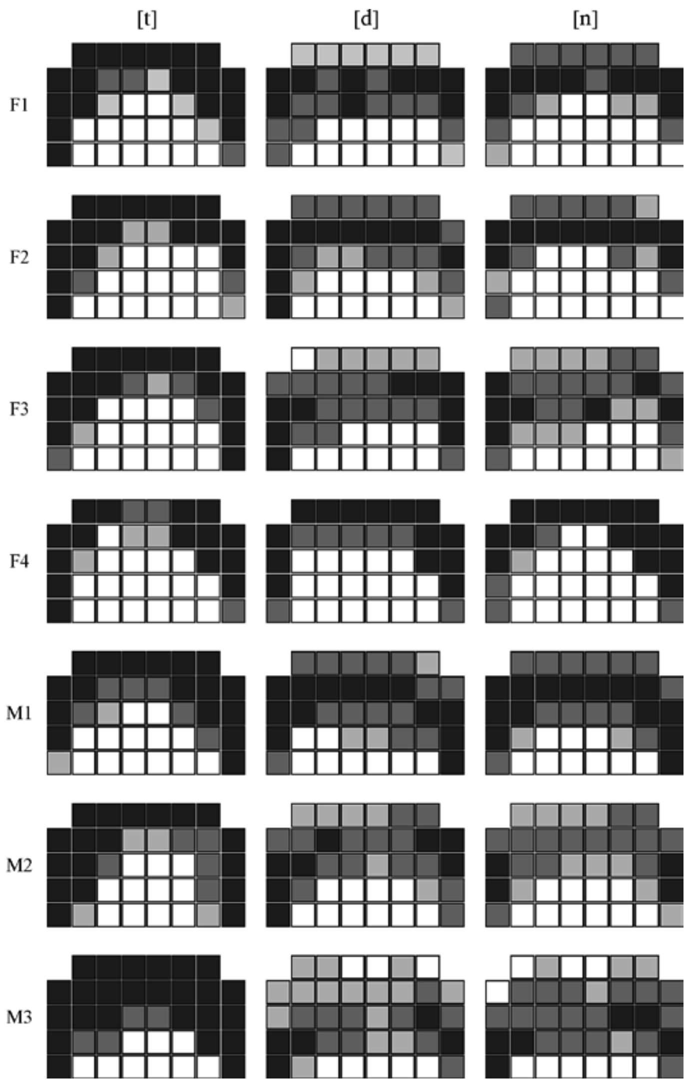

Figure 2. Composite EPG patterns of [t], [d] and [n] for the individual speakers, displaying the ratio of contacted electrodes over 15 items for the given speechsound. (Black squares correspond to more than 90% of electrodes contacted; dark grey squares to 50–90% contacted, and light grey squares to 25–50% electrodes contacted.) Only the first five rows of the palate are displayed (see text).

schematic EPG displays suggest that the place of articulation of [t] is more anterior than [d] in all speakers but F4. Moreover, the degree of this difference appears to be considerably greater than assumed by Hála (1962).

Before we turn to the quantification of these differences, let us examine the EPG pattern of [n]. Again with the exception of speaker F4, [n] manifests more contact in the second than in the first row. In some speakers, [n] appears to pattern clearly with [d], while in others (especially in speaker F1 and also speaker M3) [n] seems to "lie between" [t] and [d].

Procedures for data reduction have been mentioned in section 2. Of those proposed in literature, it is particularly the *contact anteriority index* (*CA*) introduced by Fontdevila et al. (1994) which is useful for quantifying even fine differences in the place of articulation. For our purposes, we have adapted the CA index so that only the four anterior rows are taken into account. As the calculation in (1) shows, the index is a weighted sum of activated electrodes in the given frame. The CA index is superior to other indices in that the weights allow for better identification of the most anterior contact in the given speechsound: "the contribution of a single activated electrode on a given row or column is always higher than the joint contribution of all the activated electrodes on previous back rows" (see Fontdevila et al., 1994: 144f. for more detail):

$$\mathrm{CA} = \log((R_4/8) + 9(R_3/8) + 81(R_2/8) + 547(R_1/6)+1) \;/\; \log(639) \qquad (1)$$

where R_i equals the number of activated electrodes on the i-th row. The properties of the contact anteriority index are exemplified in Table 2. The minimum value in each cell corresponds to only one electrode being activated in the respective row, while the maximum value corresponds to all electrodes on that row being activated along with all electrodes on more posterior rows. Thus the CA index of 0.3729 would be obtained if a single electrode in the second row is activated; the value of 0.3712 would be obtained by contact of all electrodes in the third and fourth row; the value of 0.6 means that the most anterior contact is located in the second row and that some other electrodes in that row and in R_3 and R_4 have been activated.

Table 2. The ranges of CA, indicating the same degree of contact (see text for details).

Row	CA range
1	0.7003–1.0000
2	0.3729–0.7000
3	0.1167–0.3712
4	0.0000–0.1073

The contact anteriority index therefore represents every EPG pattern (every target speechsound) by one single value and, at the same time, reflects exactly what we are interested in in this study: the relative frontness or backness of the place of articulation of [t], [d] and [n]. The results of the analysis of variance (ANOVA) for all speakers together, with CA INDEX as the dependent variable, are illustrated in Figure 3.

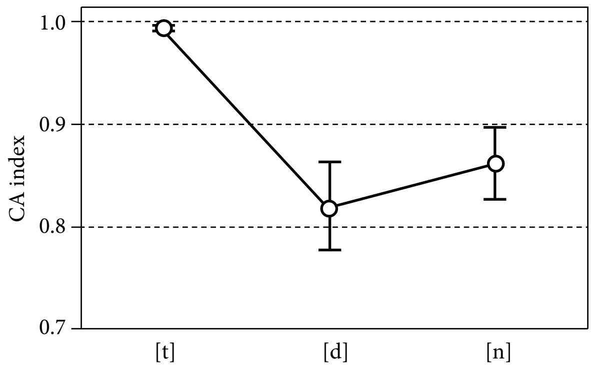

Figure 3. Contact anteriority (CA) index of [t], [d] and [n] (the vertical bars indicate 95% confidence intervals). $F(2, 312) = 32.5$; $p < 0.001$.

This general display supports our impressionistic comparison of the contact patterns presented in Figure 2: [t] is articulated more in the front than both [d] and [n] (Fisher's LSD post-hoc test: $p < 0.001$), while [n] lies between [t] and [d] but its pattern is more similar to [d] (the difference in CA between [d] and [n] is not significant, Fisher: $p > 0.05$). Also, we can see that the production of [t] is much less variable; that reflects the fact that virtually all electrodes in the first row have been contacted in [t] (*cf.* Figure 2).

In Figure 4, we examine the realization of the three target speechsounds by the individual speakers. Again, the tendencies observed in the composite EPG patterns are confirmed. The difference in CA between [t] and [d] is highly significant (Fisher: $p < 0.001$) in speakers F1, F3, M2 and M3 and significant in speakers F2 and M1 ($p < 0.05$). Also, the nasal [n] lies closer to [d] than to [t] in these six speakers.

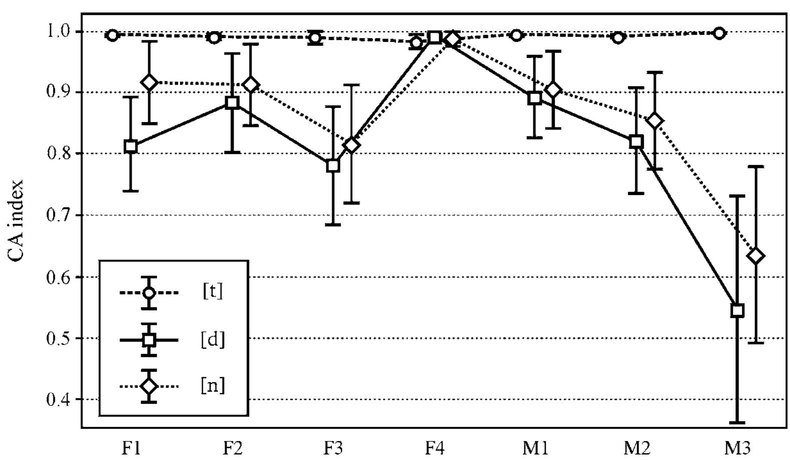

Figure 4. Contact anteriority (CA) index of [t], [d] and [n] for the individual speakers. $F(12, 294) = 4.8$; $p < 0.001$.

Our results therefore indicate that the place of articulation of [t] and [d] in Czech is indeed different and that the difference is certainly not negligible and caused merely by the aerodynamics of the fortis–lenis distinction, as suggested by Hála (1962) and Borovičková and Maláč (1967). The voiceless [t] appears to be denti-alveolar or alveolar, while the linguopalatal contact in the voiced [d] extends well into the postalveolar zone. Furthermore, the nasal stop [n] tends to pattern more with [d], making its place of articulation also between alveolar and postalveolar. The only exception is speaker F4 whose pronunciation of all target sounds – [t], [d] and [n] – is very similar.

In the following section, we are going to examine the greater variability of contact patterns in [d] than in [t]. Although this is partly caused by the way CA is calculated (see Table 2), the illustration in Figure 2 does indicate more variability – the reason for this appears to lie, at least to some extent, in the vocalic environment.

3.2 The effect of coarticulation

The nature of the words which were analyzed in this study – the target speechsounds always being flanked by the same vowel (see Table 1) – allows us to investigate the effect of vocalic coarticulation on the tongue–palate contact patterns. For the sake of simplicity, only the vowels [ɪ], [a] and [u] (i.e., the peripheral short vowels of Czech) will be considered here. Figure 5 illustrates the differences in contact patterns in the first four rows for speaker F1, who manifests similar tendencies to most other speakers (naturally, speaker F4 is an exception; see section 3.1). It is clear that linguopalatal contact is strongly affected by the surrounding vocalic context, and more so in [d].

Differences in the degree to which EPG patterns change due to the flanking vowels may be quantified using the *coarticulation index (CI)*, which was proposed by Farnetani (1990; quoted in Hardcastle et al., 1991). The coarticulation index is calculated as the mean absolute difference between the percentages of contacted electrodes on the (in our case) four rows in each vocalic context. For the sake of illustration, let us consider speaker F1's realizations of [t] and [d] in Figure 5. In the first row of [t], all electrodes were contacted in all contexts, hence the absolute difference between the percentages is 0. In the second row, the contact in [ɪ] is weaker and the absolute difference between the

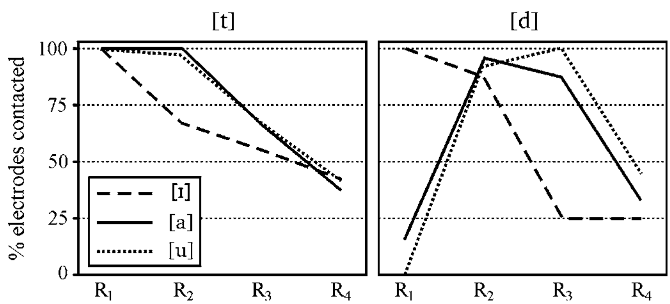

Figure 5. Contact in the first four rows (R_1–R_4) of the artificial palate in [t] and [d] depending on the neighbouring vowels. (Only data for speaker F1 are shown since idiosyncratic tendencies would partly blur the results; however, speaker F1 represents the behaviour of other speakers.)

three percentage values is 0.67. In the third row, the difference is 0.25, and in the fourth row 0.08. A mean of these four values, the coarticulation index for this speech sound, is 0.25. For [d], the absolute differences for R_1–R_4 are 2; 0.17; 1.5; 0.42, respectively, and the coarticulation index is thus 1.02.

Since we have identified divergent contact patterns between our individual speakers (*cf.* section 3.1), the difference between CI for [t] and [d] was calculated separately for each speaker and submitted to a t-test for repeated measures. The result is statistically significant, with CI being higher for [d] than for [t]: $t(6) = 4.538$; $p < 0.005$. If speaker F4 is not considered in the analysis, the difference is even greater: $t(5) = 9.588$; $p < 0.001$, with CI ranging from 0.19 to 0.41 for [t] and from 0.97 to 1.39 for [d].

This result indicates that [d] is much more susceptible to coarticulation than [t]. The ability of an articulatory gesture belonging to one speechsound to resist encroachments by gestures belonging to neighbouring consonants has been termed *coarticulation resistance* by Bladon and Al-Bamerni (1976). Coarticulation resistance depends on the degree to which the two articulatory gestures share speech organs; see Farnetani (1999) for a review.

Some studies of coarticulation resistance may be related to our investigation of Czech [t] and [d]. First, we will mention the study by Bladon and Nolan (1977) who investigated alveolar segments in English RP and found laminal speechsounds ([s z]) to manifest more coarticulation resistance than apical speechsounds ([t d n l]). The authors assume that the reason is a greater distance of the tongue dorsum active in vocalic gestures from the tongue tip than from the tongue blade. Second, Recasens (1999) reports studies which show that voiced dental or alveolar stops are affected by coarticulation more than voiceless ones.

Naturally, electropalatography only provides information about the contact of the tongue on the artificial palate and not about the part of the tongue which has made the contact. Another method would have to be applied to examine whether Czech [t] and [d] also differ in apicality *vs* laminality, but informal observations of several phoneticians indicate that they do: [t] appears to be lamino-dental and [d] apico-alveolar. If this is indeed the case, our results regarding coarticulation resistance would corroborate the above-mentioned findings in both respects: it is [t] – a laminal and voiceless sound – which manifests stronger coarticulation resistance than [d] – an apical voiced sound. It appears that the greater resistance to coarticulation in voiceless stops may be construed as a correlate of tenseness (see Skarnitzl, 2011 for correlates of tenseness in various phonetic domains).

Let us now examine in more detail the effect of neighbouring vowels on the tongue–palate contact observed in Figure 5 (as mentioned above, only data for speaker F1 are shown but they correspond to the tendencies found in most other speakers). The greatest difference can be observed in [ɪCɪ] sequences whose patterns, in the closure phase of both [t] and [d], are clearly distinguished from those in [aCa uCu] sequences.

The results are more straightforward for [d], a speechsound with a more posterior place of articulation and, as we have seen, a greater tendency to undergo coarticulatory changes. The strong contact in the first row in [ɪdɪ] sequences seems to be caused by coarticulation of [d] with a front vowel, while the strongest contact in Row 2 and Row 3 in [ada udu] sequences corresponds to the more posterior articulation of [d].

In [t], there is almost invariably complete contact in the first row regardless of the flanking vowels – that is to be expected in a denti-alveolar sound – but markedly weaker in the second row when [t] is surrounded by [ɪ]. This may be caused by the requirement of distinctiveness. The realization of a "front" consonant like [t] with neighbouring high front vowels may require a more careful coordination of the articulatory gestures. A stronger linguopalatal contact in the second row of the artificial palate may result in a greater degree of blending of the consonantal and vocalic tongue blade gestures, which may, in turn, lead to the generation of friction. It would therefore be for the sake of maintaining a sufficient contrast between the "interfering" gestures – those pertaining to the vowel [ɪ] and the consonant [t] – that the tongue is lowered behind the closure when [t] is surrounded by [ɪ].

4. Conclusion

The objective of this study was to determine the extent to which the place of articulation is asymmetrical in Czech speechsounds which are defined as alveolar stops. Of the seven speakers whose EPG patterns were analyzed, six demonstrate a significant difference between the articulation place of [t] and [d], with the latter being produced with a more posterior closure. A more accurate account of Czech stops would have to state that [t] is a denti-alveolar sound and [d] an alveolar or even post-alveolar sound. Since the earliest reports about this asymmetry are over 100 years old, it would appear that it forms a stable characteristic of the Czech sound system. The nasal stop [n] tends to lie closer to [d] as far as its articulation place is concerned. Interestingly, the seventh speaker, F4, realized all three sounds almost identically; however, her [d] did not sound dentalized to the author (a dental realization of /d/ is regarded as a speech defect in Czech).

We were also interested in questions related to more general phonetic theory. Since our observations indicate that Czech [t] and [d] also differ in the role of the tongue tip and blade, comparing linguopalatal patterns in different vocalic environments allowed us to indirectly try to disentangle the effect of the apical *vs* laminal character of the stop and of its voicing on the degree of coarticulation resistance manifested by the given speechsound. Our analyses suggest that the voiced, apical [d] undergoes more coarticulation, which also explains the higher variability observed in the contact anteriority index (see Figure 4).

The documented asymmetry in the place of articulation of Czech alveolar plosives opens a new range of research questions. One of them, which we will attempt to answer in a future study, concerns the completeness of voicing assimilation and neutralization: it may well be that the linguopalatal contact will be different in the coda of *let* (*flight*) and *led* (*ice*), depending on the voicing status of the following segment. Electropalatographic data will thus be applied not only to examine articulatory patterns but also to answer questions related to phonological theory.

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ASYMETRIE U ČESKÝCH ALVEOLÁRNÍCH OKLUZIV: ELEKTROPALATOGRAFICKÁ STUDIE

Resumé

Dřívější neformální pozorování naznačovala přednější místo artikulace u českého [t] než u [d] či [n], což je z hlediska mezijazykového srovnání jev relativně neobvyklý. Cílem studie je ověřit existenci této asymetrie v místě artikulace objektivně pomocí elektropalatografie a také porovnat lingvopalatální kontakt v různých vokalických kontextech. Výsledky ukazují, že i přes mírně odlišné tendence u jednotlivých mluvčích je [t] realizováno s přednějším místem artikulace než [d] u šesti ze sedmi analyzovaných mluvčích. Navíc se zdá, že [t] více odolává koartikulaci, což se shoduje se studiemi, které naznačují vyšší míru koartikulační rezistence u neznělých a laminálních hlásek než u znělých a apikálních hlásek jako [d].