Why are Voiced Affricates Avoided Cross-linguistically? Evidence from an Aerodynamic Study.

Marzena Zygis[1], Susanne Fuchs[2]

Zentrum für Allgemeine Sprachwissenschaft, Berlin
[1]marzena@zas.gwz-berlin.de, [2]fuchs@zas.gwz-berlin.de

Abstract

This paper shows that several typologically unrelated languages share the tendency to avoid voiced sibilant affricates. This tendency is explained by appealing to the phonetic properties of the sounds, and in particular to their aerodynamic characteristics. On the basis of experimental evidence it is shown that conflicting air pressure requirements for maintaining voicing and frication are responsible for the avoidance of voiced affricates. In particular, the air pressure released from the stop phase of the affricate is too high to maintain voicing, which in consequence leads to a devoicing of the frication part.

1 Introduction

Phonemic inventories of the world's languages show various types of gaps which are accounted for by appealing to the phonetic properties of the sounds under question. ([1]).The present investigation expands the list of sounds which are avoided cross-linguistically. It shows, namely, that voiced sibilant affricates ([d͡z], [d͡ʒ]) tend to be eliminated from phonemic inventories. At the same time, their voiceless counterparts [t͡s], [t͡ʃ] show a different behavior: the affricates are stable and they create a part of many phonemic inventories. This observation also holds for languages with a complete voicing contrast in coronal stops and fricatives.

Slavic languages undoubtedly serve to put forward the hypothesis that voiced affricates are avoided. In almost all Slavic inventories (except for Polish and Slovak), these phonemes are either not present or they occur in a very limited number of (foreign) words; see e.g. Czech phonemic inventory in Table 1.

Table 1. *Czech phonemic system.*

	dental/ alveolar	palato-alveolar	palatal
fricative	s z	ʃ ʒ	
affricate	t͡s	t͡ʃ	
stop	t d		c ɟ

Romanic languages do not prefer voiced affricates either. The only difference between Slavic and Romance languages is that the former also display voicing contrast in stops and fricatives, whereas the latter show voicing symmetries in stops only. For example, the Romanian coronal inventory contains the following obstruents: /t d s ʃ t͡s t͡ʃ/. Similarly, in the inventory of Galician, voiced fricatives and voiced affricates are not attested. The systems consists of /t d s ʃ t͡ʃ/.

There are at least two Germanic languages relevant for the present discussion. In German, /t d s ʃ z t͡s t͡ʃ/ are part of the phonemic inventory while the voiced affricate /d͡ʒ/ only occurs in words of foreign origin. But even there they tend to be devoiced, see section 3 for examples. In Yiddish, the voicing opposition in coronal obstruents is symmetrical except for affricates which are limited to the voiceless /t͡ʃ/.

In summary, the investigation of sibilant inventories of several languages shows that affricates show an asymmetry in voicing: voiced affricates are considerably less frequent than their voiceless counterparts. In many languages their status is either marginal, i.e. they occur in foreign words only, as for example in Slovene or Bulgarian, or they do not occur at all, as in Russian or Yiddish.

2 Typology of voicing

The avoidance of voiced affricates is confirmed if we compare the frequency of occurrence of voiced coronal affricates with voiceless ones as well as stops and fricatives.

Figure 1 provides such a comparison based on the UCLA Phonological Segment Inventory Database ([2]) containing the phonemic inventories of 451 languages.

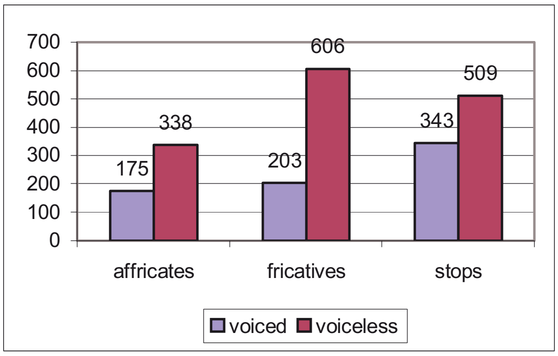

Figure 1: *Frequency of occurrence of voiced and voiceless obstruents based on the UPSID database*

In all three classes, i.e. affricates, fricatives, and stops, it is the voiceless segment that occurs more frequently than the voiced ones. More importantly, voiced affricates are the least frequent phonemes cross-linguistically. How can we explain such asymmetry?

3 Avoidance of voiced affricates

In our view the avoidance of voiced affricates is attributable to the following aspects: 1) articulatory complexity, 2) etymology of the sounds, and 3) aerodynamic requirements.
The articulatory complexity refers to the fact that affricates consist of two phases: a stop phase with an articulatory closure followed by a fricative phase where the closure is released into a midsagittal groove and lateral tongue-palatal contacts.

The lower frequency of the affricates could also be attributed to the fact that they are not primitive sounds but have predominantly developed from stops.

However, it should be noted that neither the articulatory complexity nor the roots of voiced affricate fully explain the asymmetry between voiced and voiceless affricates as the two-phased articulation is found in both sound groups and both voiced and voiceless affricates developed mainly from stops.

What is the most important aspect in explaining the avoidance of voiced stops is their complex aerodynamics. Note that in all three classes, i.e. affricates, fricatives and stops, it is the voiceless segment that occurs more frequently than the voiced one. Thus, the conclusion can be drawn that the inherent properties of voicing including aerodynamic conditions and laryngeal-oral coordination are responsible for the asymmetry found in phoneme inventories. The complex aerodynamic conditions refer to the fulfilment of two conflicting pressures simultaneously in the fricative release: a low oral pressure for maintaining voicing and a high oral pressure ensuring sufficient air velocity for creating frication, cf. [3].

4 Experimental evidence

The aerodynamic experiment was designed to gain a better insight into the aerodynamics of voiced affricates in contrast to voiceless ones, but also to compare aerodynamic conditions in the production of stops, fricatives and affricates. For this purpose, three simultaneous recordings were obtained: (i) intraoral pressure changes, (ii) airflow at the mouth, and (iii) the audio-signal.

All recordings were obtained by using PCquirer (version 5.0). The audio-signal was recorded at a sampling rate of 22500 Hz for the intraoral pressure and of 2750 Hz for the airflow. The data were subsequently imported into Matlab for further filtering, calculation of derivatives, and segmentation.

Four native speakers of German and four native speakers of Polish (two female and two male) took part in the experiment. Each subject was equipped with a Rothenberg mask and additionally, a piezo-resistive pressure transducer was glued onto the back part of the palate (Endevco 8507C-2) to measure intraoral pressure differences.

The speech material consisted of words containing coronal voiced and voiceless obstruents:

a) German: stops /t d/, fricatives /s z ʃ ʒ/ and affricates /t͡ʃ d͡ʒ/

b) Polish: stops /t d/, fricatives /s z ɕ ʑ/ and affricates /t͡s d͡z t͡ɕ d͡ʑ/

All words were bisyllabic with a stress falling on the first syllable. The subjects were asked to read all presented words embedded in a frame sentence and to repeat each sentence five times.

4.1 Labeling procedure

The following time landmarks were labeled: i) consonant on- and offset on the basis of 2nd derivative (acceleration peaks) of the filtered pressure signal (see figure 2), ii) the voicing offset and iii) the time point where the intraoral pressure slope starts to change (Koenig & Lucero, 2008) as the deceleration peak in the 2nd derivative. The pressure peak has been obtained automatically by searching for the maximum between on- and offset.

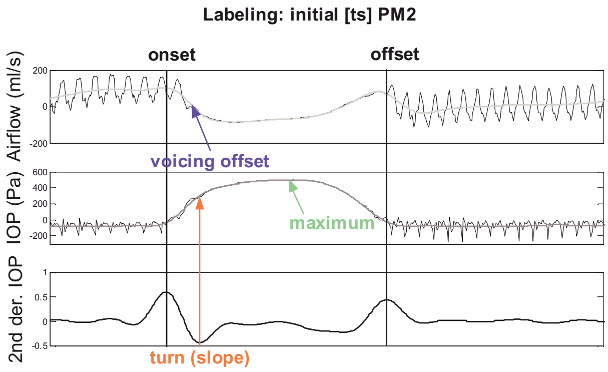

Figure 2: *Labeling criteria: 1st track: airflow, 2nd track: intraoral pressure, 3rd track: 2nd derivative of the filtered pressure signal; black: raw data, gray: filtered data*

4.2 Results

So far the data for all the Germans and 2 Polish speakers were analyzed and will be discussed. Because of the limited space here, the various phonemes were pooled into groups of fricatives, stops, and affricates.

4.2.1 Temporal results

Figure 3 displays the means for the overall duration of the segments (note that in the German (G) data 4 speakers are included, but for the Polish data (P) only 2). As can be seen, for the German speakers the affricates are the longest segments, no matter whether they are phonologically voiced or voiceless, or whether they occur in word initial or medial position.

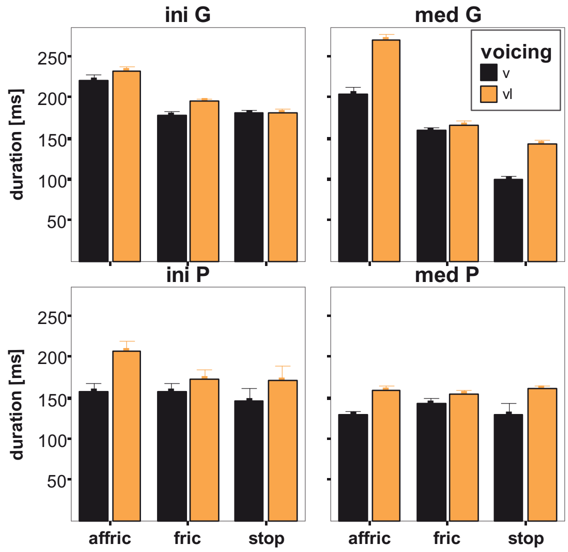

Figure 3: *Means of overall duration (in ms) for affricates, fricatives and stops; v=voiced (black bars), vl=voiceless (grey/orange bars); errors bars correspond to +/- 1 std. error*

Figure 4 exemplifies the temporal results for voiced and voiceless portions of the relevant segments in more detail for the Polish speakers.

In most cases phonologically voiced obstruents are fully voiced and phonologically voiceless obstruents show voiced portions with a duration below 50 ms. For the German speakers a larger inter-speaker variability was found: in some cases results are similar to the Polish data, and in other cases even the phonologically voiced phonemes were produced with very short voicing and long voiceless portions.

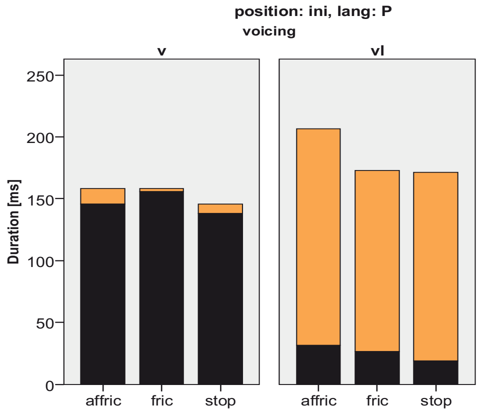

Figure 4: *Stacked bar plots for means of voiced and voiceless portion; left: phonologically voiced obstruents, right: phonologically voiceless obstruents; Polish speakers, initial position*

4.2.2 Intraoral pressure peaks

The intraoral pressure peak is not a very reliable value to draw any further conclusions about the phonological voicing status of a segment, in particular not for affricates. Since these segments are so long in duration, voiced and voiceless phonemes often reach a comparable maximum (IOP equalizes subglottal pressure).

4.2.3 Intraoral pressure rise (slope)

Koenig and Lucero (2008) proposed that differences in voicing contrast are reflected in the slope values of the intraoral pressure rise. We adapted this method and calculated the slope from the onset of pressure rise to the first turning point (see fig.2). The results of this measure are displayed in figure 5. Since all data behaved in the same direction, they are pooled together here. Voiced phonemes consistently show a slow pressure rise with lower slope values, while the voiceless ones display a quick rise with considerably higher slope values. In terms of articulation, a slow intraoral pressure rise can be associated with a closed glottis and a closed vocal tract, whereas a steep slope (quick rise) is realized due to an open glottis (intraoral pressure equalizes subglottal pressure) and a closed vocal tract. However, even when voiced affricates show a slower pressure rise, they often reach the same pressure maximum and a threshold where voicing is difficult to maintain. The relatively long duration of the affricates (as observed for German speakers) may on the one hand speak for the articulatory complexity of this sound. On the other hand, it is very likely that it contributes to the devoicing of voiced affricates since the transglottal pressure difference can not be maintained for a long time with a constricted vocal tract.

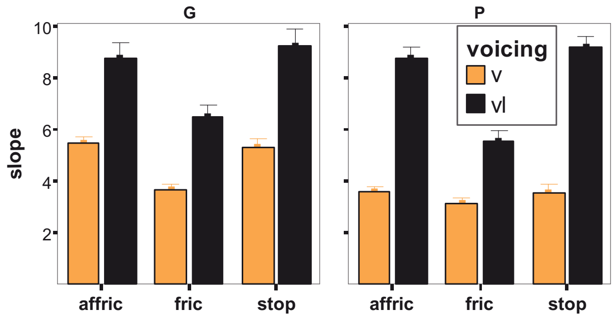

Figure 5: *Bar plots for means of voiced and voiceless slope values for the intraoral pressure rise; left: all German data, right: all Polish data; split by affricates vs. fricatives vs. stops*

5 Conclusion

Based on a typological study and experimental results, we conclude that voiced affricates are avoided in the sounds of the world's languages for temporal and aerodynamic reasons. Although intraoral pressure rises more slowly in voiced affricates, it often reaches a similar pressure peak as in its voiceless counterpart. Voicing may also be difficult to maintain since affricates are so long in duration.

6 References

[1] Maddieson, I. Patterns of Sounds. Cambridge University Press, Cambridge, 1984.

[2] Maddieson, I. & K. Precoda. UPSID and Phoneme. UCLA Phonological Segment Inventory Database Version 1.1. 1992.

[3] Ohala, J. J. The origin of sound patterns in vocal tract constraints. In: MacNeilage, P. F. (ed.) The Production of Speech. Springer Verlag, New York, 1983, 189-216.

[4] Koenig, L.L. & Lucero, J. Stop consonant voicing and intraoral pressure contours in women and children. *JASA* 123, 1077-1088, 2008.