Voiced fricatives in Hungarian

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Introduction

In this paper we describe the acoustic properties of voiced fricatives, namely /v/, /z/, and /ʒ/, in utterance-final and word-final utterance-medial position in Hungarian, in comparison to their voiceless counterparts, namely /f/, /s/, and /ʃ/. The experiments presented here are in line with a larger study focusing on the phonetic underpinnings of the phonology of voiced fricatives in Hungarian. In recent studies (Kiss & Bárkányi 2006; Bárkányi & Kiss 2010), it has been demonstrated that the double-faced phonological behaviour of /v/ in Hungarian can be explained in a model based on the phonetic properties of this segment and its linear context. The analysis is based on the claim that the phonetic targets of /v/ are contradictory on aerodynamic grounds (Ohala 1983) and can only be maintained in phonetically favorable positions.

In connection to voiced stops, Westbury & Keating (1983) explain that intervocalic word-medial position assures appropriate conditions for voicing, as opposed to the utterance-initial position, where the acoustic and articulatory conditions of phonation have to be built up (e.g., subglottal pressure, vocal fold position). In utterance-final position, subglottal pressure can be expected to decrease due to an increasing inspiratory force. These articulatory circumstances hold for voiced fricatives as well; maintaining friction and voicing at the same time is a further complication. It is well known that for the articulatory system to target voicing and friction (turbulent noise), an uneasy balance needs to be maintained. High-amplitude turbulent noise requires a relatively high-volume velocity of the airflow as it blows out from a constriction. In order to achieve this condition, the glottis is widely abducted so that the intraoral pressure equals or approaches the subglottal pressure, and the oral cavity is relatively constricted, creating a pressure drop across the supraglottal constriction (see among others Shadle 1985; Stevens et al. 1992; Stevens 1998; Jesus 2001; Johnson 2003: 120–133; Krane 2005).

In contrast, for vocal fold vibration to be initiated, the vocal folds must be set into modal phonation mode: they must be adducted, and subglottal air pressure must build up below the adducted vocal folds, forcing the lower part of the folds to blow apart (with the consequence that subglottal pressure drops close to zero relative to atmospheric pressure); and the negative pressure created as air passes between the folds must suck the elastic folds together again (Bernoulli effect). If the pressure above the folds builds up so that the pressure difference drops across the glottis, phonation ceases, so it is an important condition that there be transglottal pressure difference throughout the production of voiced fricatives. To overcome devoicing, a number of articulatory gestures, which aim at preserving a transglottal difference of pressure, need to be implemented to enlarge the oral cavity volume: e.g., raising the soft palate, advancing the tongue root so that there is an outward movement of the neck surfaces, lowering the larynx, expanding the pharyngeal volume, decreasing the stiffness of the vocal tract walls (reducing vocal tract compliance), or a combination of these gestures (Stevens 1998: 465–486). These gestures, however, can only be executed within certain limitations, which might have phonological consequences.

Bárkányi & Kiss (2010) found that /v/ in post-consonantal utterance-final position (e.g., *kedv* 'mood') contained unvoiced frames in 81.1% and in post-vocalic utterance-final position (e.g. *sav* 'acid') it was devoiced in 56.5%. The only other context in which /v/ was realized with more than 50% of unvoiced frames was before a voiceless obstruent (67.1%). Bárkányi & Kiss (2009a) compare /v/ and /f/ realizations in utterance-final position with the help of nonsense words ending in vowel-sonorant /v/ or /f/. They also found that /v/ in this position was realized as a voiceless fricative with 76.81% of unvoiced frames (opposed to 88.42% of unvoiced frames in /f/) and a harmonicity median of 2.68 dB (1.02 dB for /f/). See the section on methods for an explanation of harmonics-to-noise (HNR) ratio.

The above mentioned conflicting aerodynamic requirements and complex articulatory gestures are expected to hold for the other voiced fricatives as well, not only /v/; therefore, we assume that /z/ and /ʒ/ in Hungarian in phonetically unfavourable positions – like the utterance-final position, for instance – also devoice, as observed in Bárkányi et al. (2009) and Gráczi (2010).

The main goal of the present article is to compare the fricatives along the places of articulation and investigate whether all voiced fricatives devoice to the same extent in utterance-final position and whether the acoustic properties of labiodentals are significantly different from the other two fricative pairs, which could explain their different behaviour in voicing assimilation. In our study all the fricatives appear in the same context and are read by the same speakers. In this way we can exclude possible speaker-dependent differences observed in earlier studies (Bárkányi & Kiss 2009b; Gráczi 2011) and can shed light on the different strategies of voicing contrast preservation. In the following parts we present the results of an acoustic analysis focusing on the voicing contrast of Hungarian fricatives in utterance-final and word-final utterance-medial position.

Methods

In the present paper we chose to examine non-words (logatoms) of the form *lala*C in utterance-final (henceforth final position) and – as a control – in word-final, utterance-medial positions (henceforth medial position) where C is one of the following six fricatives: /v/-/f/, /s/-/z/ and /ʃ/-/ʒ/. We used non-word data so that all the phonetic parameters under scrutiny could be controlled for. The carrier sentences were "A képernyőn a *lala*C alak látható" and "A képernyőn látható szóalak a *lala*C". Both mean 'The word *lala*C can be seen on the screen.'

Recordings were carried out in a silent room, with AT 4040 microphone at 44.1 kHz and 16 bit. Sentences were introduced in random order through headphones in SpeechRecorder (Draxler & Jänsch 2004). Twelve native speakers of Standard Hungarian (6 males and 6 females) participated in the experiment. None of them reported any hearing loss or speech disorders. Their ages were between 24 and 29.

We measured the following parameters:

a) fricative voicing (%): the percentage of the unvoiced part during the fricative interval
b) fricative length (ms): the duration between the on- and offset of the friction due to the oral constriction, in case of sonorant-like realizations, between the midpoints of the sound transitions (based on the formant and intensity contour)
c) length of the preceding vowel (ms): from the midpoint of the sound transition (based on the formant and intensity contour) between the preceding [l] and [ɔ] to the onset of the following fricative (see above)
d) voicing of the preceding vowel (%): the percentage of unvoiced part during the preconsonantal segment (preaspiration was considered as part of the preceding vowel)
e) harmonics-to-noise ratio in the target consonant (dB) (see below)

The starting and end point of the consonant and the preceding vowel, and the end and restart of voicing were manually labelled by the authors based on the waveform and the spectrogram. As long as periodicity was observable in the lower frequency region and in the waveform, the given sound part was labelled as voiced, including creaky voice and breathy phonation. In case of pre- or post-aspiration, the aspirated part was treated as belonging to the vowel, while the starting and end points of the consonants were set at the onset and offset of the observable friction characteristic for the given consonant (Fig. 1) or, in case of sonorant-like realizations at the midpoints of the sound transitions, based on the formant and intensity contour. Labelling and further acoustic analyses were carried out in Praat 5.2 (Boersma & Weenink 2011).

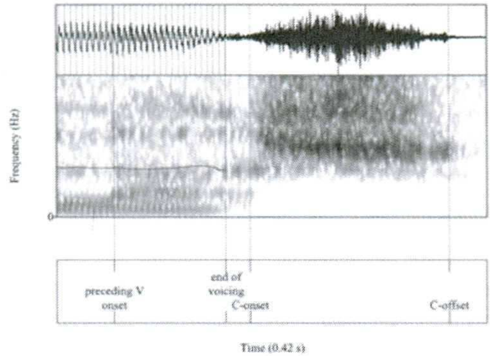

Figure 1. Sample of labelling (utterance-final [lɔʃ] pronounced by a female speaker)
Top: Waveform and pulses (voicing automatically detected). Middle: Spectrogram and pitch.
Bottom: Labels.

In order to compare the relation between voicing and friction, we used the mean of harmonics-to-noise ratio (HNR), which is the degree of acoustic periodicity in dB. The standard settings of Praat were used, except that the silence threshold was set to 0.03, as the labiodental fricatives in general were of very low intensity. Applying this method, only one realization of utterance-final /v/, two of utterance-medial /f/, and three of utterance-final /f/ could not be analysed regarding HNR. Six further consonants had to be eliminated from the HNR analysis due to additional noise. The interpretation of these values is the following (see Boersma 1993 for details): A harmonicity median of 0 dB means that there is equal energy in the harmonics and in the noise signal, so it suggests a turbulent, strongly noisy realization. A mean around 20 dB indicates almost 100% periodicity, meaning a vowel-like realization.

The statistical analyses of the data were carried out in SPSS15.0. Due to the presence of non-normal distribution in some data (determined by the Shapiro–Wilk test) non-parametric tests were run (Mann–Whitney and Kruskal–Wallis). The following section presents our results.

Results and discussion

First the results of medial position will be presented. A detailed description of the acoustic properties of word-internal intervocalic voiced and voiceless fricatives can be found in Gráczi (2010). In medial position approximately a third (30.6%) of the voiced segments were realized fully voiced (Fig. 2); i.e., a fair amount of devoicing and variability is observed in this position. /z/ is more likely to devoice; there are very few truly voiced (less than 20%

unvoiced part ratio) realizations resulting in the highest unvoiced part ratio (65%±31%); this value for the postalveolar voiced fricative is 51%±30%, while for /v/ it is 34%±33%. This means that standard deviation is very similar across the places of articulation, while the amount of phonation is significantly different (Kruskal–Wallis test: $\chi^2=26.767$, $p<0.001$ for voiced fricatives; voiceless: $\chi^2=8.115$, $p=0.017$). This difference can be explained by the articulatory and acoustic differences among these places of articulation. Shadle (1997) explains that the spectral differences depend on the characteristics of the obstacle (like its shape, stiffness, etc.). Besides the physical background the articulatory targets may also differ. We can see that /v/ is subject to devoicing less frequently and to a lower degree than the sibilants. We believe this is partly due to the fact that the articulatory target for Hungarian /v/ is a narrow approximant (see Padgett 2002; Bárkányi & Kiss 2010) rather than a voiced fricative.

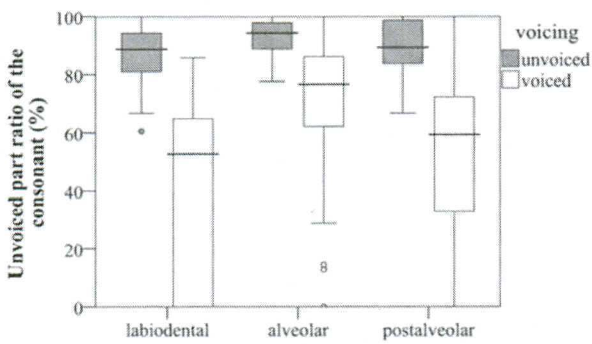

Figure 2. Unvoiced part ratio of the consonants in medial position

	Region (voiceless part ratio, %)	Frequency (%)
/f/	60.54–85.79	35.4
/v/		35.4
/s/	77.63–100	100
/z/		41.7
/ʃ/	66.67–100	100
/ʒ/		35.4

Table 1. Overlap of the fricative realizations in medial position

In order to be able to draw conclusions about voicing contrast preservation by phonation, these results must be compared to the realizations of the voiceless counterparts of these consonants. The unvoiced part ratio of the voiceless fricatives is on average higher in all cases (87%–93%), as expected, and shows lower variability (SD ranges between 6–10%), although the difference among the places of articulation is statistically significant: $\chi^2=8.115$, $p=0.017$. The question arises to what extent the contrast between the phonologically voiced and voiceless counterparts is preserved by phonation itself. Therefore, we counted how many instances of voiced realizations fall into the region of voiceless realizations, this we called "frequency of overlap". In Table 1 we can see that the frequency value for /s/ is 100%, which means that for all /s/ instances we may find a /z/ realization with the same unvoiced part ratio. This is because there were fully voiceless (100% unvoiced part ratio) /z/ realizations. We can also see that /v/ and /f/ are the farthest from each other in terms of voicing due to the reasons explained above. We also measured the overlap in devoicing between the [+voice] and [-voice] fricative pairs; this we called "overlapping region", also presented in Table 1. This range for the labiodentals is 61%–81%, which means that the most voiceless /v/ contains 81% of unvoiced part ratio, while the most voiced /f/ is devoiced to 61%. Note that these values only represent raw numerical data, so on one hand, if a [+voice] segment is just a few percentage points less devoiced than a [-voice], this does not necessarily mean that they can actually be differentiated; on the other hand, if a [+voice] and [-voice] segment agree in phonation, it does not necessarily mean that there is no contrast preservation. There might be other phonetic cues that reliably differentiate them. We can conclude that voiced–voiceless pairs significantly differ in voicing according to the Mann–Whitney test (Z is between -7.915 and -6.826, $p<0.001$). Looking at the results by speakers we find that all voiced phonemes show high intra- and inter-speaker variability; however, there is no speaker whose sibilants are always voiced, but there are two speakers whose always realize /v/ as fully voiced. We observed some, albeit lower, inter-speaker variability in the case of voiceless fricatives as well. It is the alveolar fricatives that overlap most often even in the same speaker's pronunciation.

The harmonicity median value is in close relationship with voicing. The mean values (Fig. 3) – as expected – are higher for the voiced fricatives for all three places of articulation. The difference is especially marked for /v/. The largest variability is also observed in the case of labiodentals. The results are significant across the places of articulation (Kruskal–Wallis: χ^2 was 32.375 for the voiceless segments and 27.340 for the voiced, $p<0.001$) and between the members of all voiced–voiceless pairs (Mann–Whitney: Z is between -7.876 and -5.430, $p<0.001$). This tendency is always present for at least eight speakers in the case of sibilants; labiodentals show this behaviour in all speakers' production.

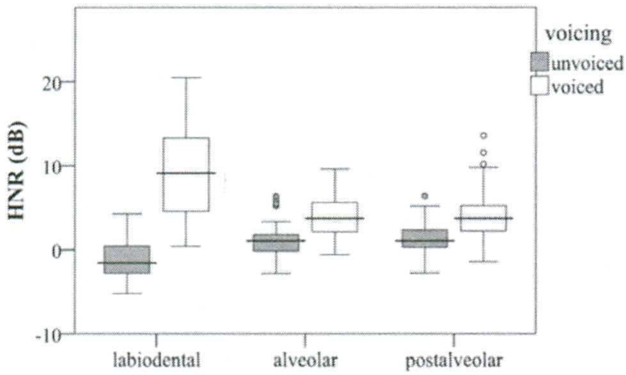

Figure 3. HNR values of the consonants in medial position

Looking into the secondary cues (other than phonation itself) we can see (Fig. 4) that in medial position fricative duration seems to play a relevant role in [voice] distinction. The unvoiced phonemes tend to be longer, with a mean around 100 ms (SD 15–17 ms), while the mean of voiced fricatives is 74–80 ms, the difference is statistically significant for all places of articulation according to the Mann–Whitney test (*Z* is between -6.479 and -4.963, $p<0.001$).

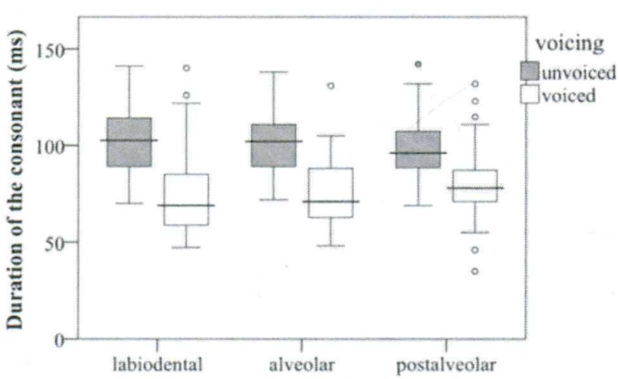

Figure 4. Duration of the consonants in medial position

Vowel duration, on the other hand, does not seem to be such a clear differentiator in this position (Fig. 5). In the case of unvoiced fricatives the mean duration of the preceding vowel is 98–99 ms. The vowels preceding the voiced fricatives are slightly longer, the difference is significant in the case of sibilant pairs (*Z* is -2.288, $p=0.022$ for /z/, *Z* is -3.803, $p<0.001$ for

/ʒ/); however, vowel length is not affected by the underlying voicing value of the following labiodental (Z is -5.018, $p=0.604$): the mean vowel duration before /v/ is 101 ms, before /z/ is 108 ms and before /ʒ/ is 113 ms. Our results reflect inter-speaker differences: only three subjects had longer vowels before /v/ than before /f/ and five speakers showed the same tendency for the alveolars, while ten speakers had longer vowels before voiced post-alveolar fricatives than preceding a voiceless one. Note that in the case of consonant duration, at least ten speakers produced longer voiceless fricatives than voiced ones for all places of articulation.

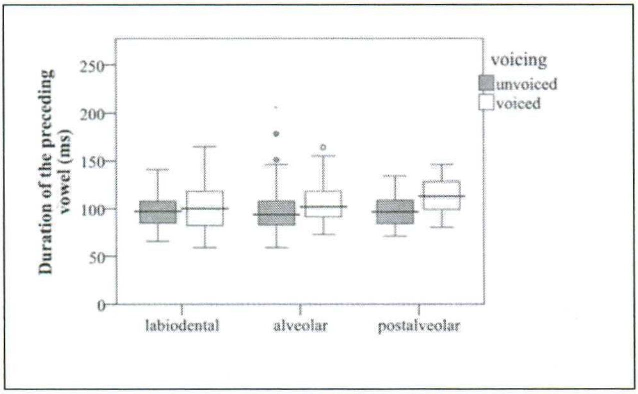

Figure 5. Duration of the preceding vowel in medial position

We will briefly discuss the utterance-final position. As expected on aerodynamic grounds, a high ratio of devoicing appeared in the realizations of the voiced phonemes (Fig. 6). In utterance-final position only the 0.7% of all voiced target phonemes were realized with vocal fold vibration during their entire duration; recall that in medial position the third of these segments were realized fully voiced, even /v/ almost always undergoes partial devoicing in final position. Thus position is a relevant factor in this case: the phonologically voiced phonemes devoice to a significantly lesser extent in medial position than in final (Mann–Whitney test: Z is between -6.051 and -3.466, $p \leq 0.001$); in fact, voiceless fricatives are also realized with higher unvoiced part ratio here. Examining the places of articulation, similar tendencies are observed as in medial position: /z/ is the most likely to devoice, and is devoiced to the greatest extent (84%±10%); this value for the postalveolar voiced fricative is 78%±16% and for /v/ 75%±21%; however, the differences are not statistically significant in final position (Kruskal–Wallis test: $\chi^2=4.847$, $p=0.089$ for the voiced fricatives, voiceless: $\chi^2=3.725$, $p=0.155$). This may be explained by the unfavourable aerodynamic conditions in this position which cause early cease of phonation across all the places of articulation.

The overlapping region between the realizations of the voiced and voiceless members (Table 2) is also smaller than in medial position due to the above mentioned higher degree of devoicing. This means that in the case of fricative devoicing in Hungarian the effect of the position is more important than that of the place of articulation. Note, however, that even in final position we found a statistically significant difference in voicing between the voiced–voiceless members of the counterparts: according to the Mann–Whitney test, Z is between -8.037 and -6.743, $p<0.001$. The question arises as to what extent this difference is relevant for perception. Bárkányi & Mády (2011) found with synthesized speech that an alveolar fricative is more likely to be perceived as voiced if the fricative is voiced in at least 30% of its duration.

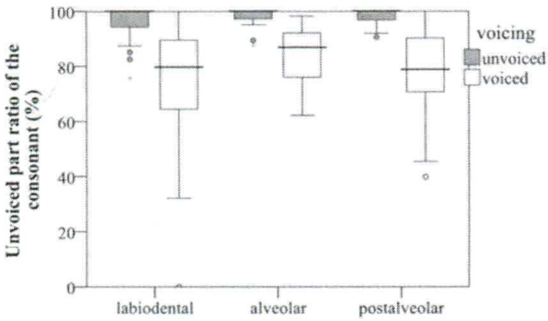

Figure 6. The unvoiced part ratio of the consonants in final position

	Region (voiceless part ratio, %)	Frequency (%)
/f/	75.82–100	100
/v/		60.4
/s/	87.45–98.23	31.3
/z/		45.8
/ʃ/	90.48–100	100
/ʒ/		22.9

Table 2. The overlap of the fricative realizations in final position

The HNR values (Fig. 7) reflect to some extent the results obtained for voicing in that the difference is statistically significant between the voiced–voiceless members of the counterparts: according to the Mann–Whitney test, Z is between -5.175 and -3.640, $p<0.001$. Contrary to the voicing results, however, statistically significant difference was found among the places of articulation for the unvoiced phonemes ($\chi^2=31.378$, $p<0.001$), which might be due to the low intensity and diffuse spectral characteristics of the labiodental fricative /f/. The same difference is not observed in the case of voiced segments because the mean HNR value of /v/ approximates that of the voiced sibilants due to its expanded dispersion towards the lower region. Both the HNR and the voicing results support the position that /v/ tends to be realized as a narrow approximant (as discussed earlier) in phonetically favourable position, while in utterance-final position due to aerodynamic reasons this articulatory target cannot be reached and thus /v/ is realized less voiced (and more fricative-like). Thus we can conclude that in final position the voiced labiodental behaves more often similarly to the voiced sibilants – i.e., it preserves some friction and loses voicing (compare Figs. 2 and 3 with Figs. 6 and 7).

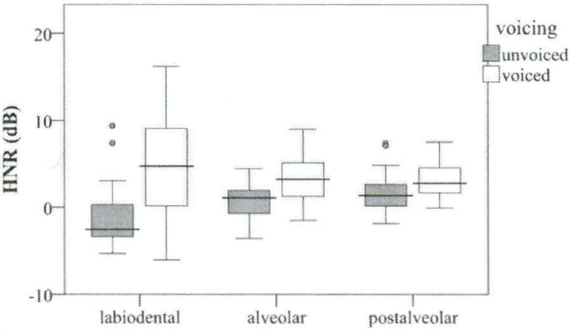

Figure 7. HNR values of the consonants in final position

Like in medial position, consonant duration is a reliable differentiator in final position as well (Fig. 8): Mann–Whitney test Z is between -7.219 and -6.628, $p<0.001$. Looking at the speakers' results, almost no overlap can be observed between the voiced–voiceless counterparts.

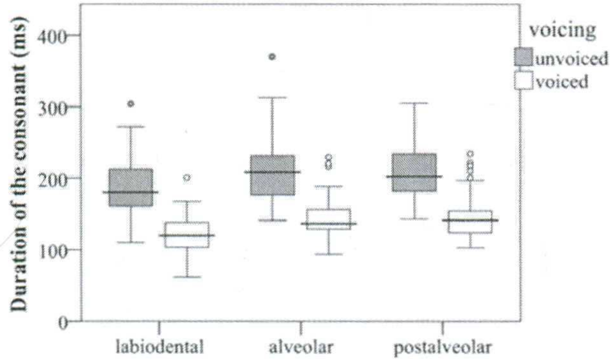

Figure 8. Consonant duration in final position

As for vowel duration (Fig. 9), in accordance with universal tendencies (cf. Maddieson 1997), longer vowel duration and shorter consonant duration can be observed for the phonologically voiced fricatives in our data, with the exception of one speaker. Although we found statistically significant differences in almost all cases, the distributions of the vowel durations show high overlaps. The duration of the vowels before the unvoiced phonemes are systematically in the lower region of those preceding voiced fricatives, 84–100% overlap with the 74–100%, respectively.

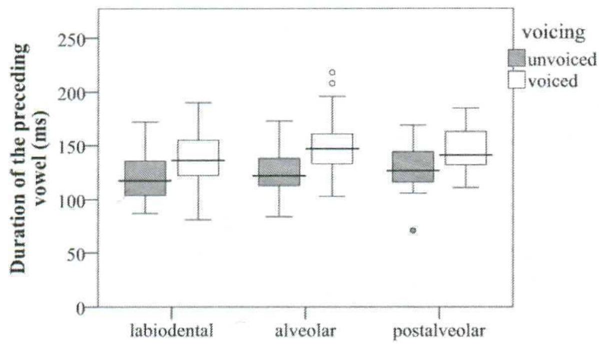

Figure 9. Vowel duration in final position

As seen above, the differences in consonant duration hold for all places of articulation, while vowel duration is not such a clear cue in medial position. The question may arise whether the difference is more pronounced but masked by the tempo of articulation. In order to answer this question we also analysed the V:C duration ratio (Fig. 10). In the case of voiceless fricatives, the mean ranged between 0.93 and 1.01 (SD: 0.18–0.62) in medial position, and between 0.64 and 0.67 (SD: 0.15–0.18) in final position, while in the case of voiced fricatives this mean was above 1.0 (1.42–1.49, SD: 0.31–0.42 in medial, and 1.02–1.24, SD: 0.25–0.43 in final position). These differences are significant for all places of articulation in both positions according to the Mann–Whitney U test (*Z* ranged between -6.986 and -5.791, $p<0.001$ in all cases). Only one of our speakers did not produce this tendency in medial position, while it was apparent for all subjects in final position and for all the others in medial position.

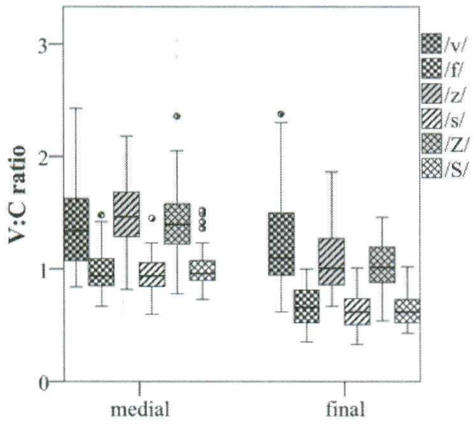

Figure 10. Consonant-vowel duration ratio in both positions (/Z/=/ʒ/, /S/=/ʃ/)

A further phonetic correlate of voicing contrast preservation in final position may be the partial devoicing of the preceding vowel. Gordeeva & Scobbie (2010) claim that preaspiration is a correlate of word-final voice in Scottish English fricatives. We also found that preaspiration accompanied only unvoiced phonemes (Table 3), but the mean value is very low for all consonants in both positions. In utterance-final position this ratio seems to be higher and, for the alveolars, longer than for the other two places of articulations. These low mean percentages are due to a low number of cases with preaspiration. In medial position 2.6–6.8% (1–3 occurrences) of the vowels were partially devoiced; this was 13.6–29.5% in final position. The five occurrences in medial position appeared in three speakers' speech, and the 33 occurrences in final position appeared in six speakers' speech. One of our speakers produced all her preceding vowels partially devoiced before all unvoiced phonemes, and another subject produced 75% of his vowels as such before alveolar and postalveolar consonants. These results suggest that preaspiration is a speaker-specific feature in Hungarian.

		/f/	/s/	/ʃ/
Medial	Voiceless part ratio	0.3±1.8	0.8±3.4	0.5±3.6
	Frequency of occurrence	2.1	2.1	6.3
Final	Voiceless part ratio	2.0±5.1	8.0±14.4	4.3±9.3

Table 3. Frequency (%) of partial devoicing of the pre-fricative segment, and the ratio of the unvoiced part (%, mean and standard deviation)

We fitted an ROC (receiver operating characteristic) analysis to our data. The ROC curve serves to illustrate the performance of a binary classifier system. It was conducted here in order to define the role the analysed acoustic features play in discriminating the voiced and voiceless counterparts from each other. In Table 4 the contingency table of the ROC space is presented – i.e., the areas under the curve for all three voiced–voiceless fricative pairs in both positions. The value of random guess is 0.500; this means that if the value is well below or well above 0.500 within the 0–1 range, the acoustic feature under scrutiny turns out to be a good differentiator. Therefore, the closer the value of the area for the given factor is to 0.500, the less role that factor can play in the separation of the members of the counterparts.

The results of the ROC analysis support those of the above described acoustic analyses. The extent of devoicing of the pre-fricative segment and its duration hardly play any role in dividing the realizations into the phonemic groups in medial position. The "strength" of these parameters, however, depends on the place of articulation, as expected based on the above numerical analyses. Consonant duration and thus the V:C duration ratio are much better differentiators, and the voiceless part ratio of the consonant and the HNR value are the best classifying factors. The slightly higher and more frequent devoicing (and thus fricativization) of the sibilants is also shown by the slightly lower area values for these segments. The results show similar tendencies for the fricatives in final position, though with some meaningful differences. Both the voiceless part ratio and the consonant duration show lower area values in this position compared to the medial position, except for the labiodentals, where the voiceless part ratio is less effective but still a strong factor in contrast preservation. The importance of these differentiating factors can be explained by the above mentioned results; that is to say, though in final position both the difference in duration and devoicing are higher in the voiced fricatives compared to their realization in medial position, a similar tendency was found for the unvoiced consonants as well. The exceptional behaviour of the labiodentals also originates in the above mentioned acoustic characteristics of these segments. In medial position, the voiced labiodentals are mostly realized as narrow approximants; their voicing features play a clear, evident role in separating them from /f/, while in final position, /v/ loses its approximant-like behaviour and approaches a more fricative-like realization. The V:C ratio and the HNR values are reliable differentiators in final position as well; however, the area values for the HNR lower somewhat compared to the medial position due to the higher devoicing of the voiced consonants, which causes a higher ratio of friction in these segments. The changes in the possible differentiating role of vowel duration and devoicing are also dependent on the place of articulation. Their role is still not high compared to the other examined factors, but somewhat stronger than in medial position. There is an exception again: vowel duration before the postalveolars loses its importance slightly.

	Medial			Final		
Variables	labio-dental	alve-olar	post-alveolar	labio-dental	alve-olar	post-alveolar
C devoicing	0.028	0.107	0.065	0.127	0.034	0.059
C duration	0.156	0.125	0.200	0.079	0.102	0.121
V devocing	0.488	0.466	0.488	0.439	0.349	0.395
V duration	0.539	0.642	0.730	0.691	0.774	0.709
V:C ratio	0.868	0.939	0.902	0.927	0.919	0.892
HNR (dB)	0.978	0.800	0.816	0.795	0.767	0.699

Table 4. Results of the ROC analysis: the area under the curve

Conclusions

The focus of the present study is the behaviour of word-final, especially utterance-final fricatives in laboratory speech: their voicing, and the role some other phonetic correlates might play in contrast preservation.

The results of the unvoiced part ratio of the fricative pairs are in accordance with our expectations based on universal tendencies in fricative voicing. Utterance-final voiced fricatives undergo devoicing, which leads to overlapping realizations with their voiceless pairs. This devoicing gesture is less enhanced in utterance-medial position, still resulting in high overlaps. Despite devoicing, the difference in phonation is statistically significant in both positions for all voiced–voiceless counterparts.

The other phonetic cues that are considered universal distinguishing features of voicing contrast preservation are shorter consonant but longer preceding vowel duration for the voiced phonemes, which is only partially present in our data.

In accordance with earlier studies, our data also suggest that the voiced labiodental is a narrow approximant rather than a true voiced fricative, which is overridden by the unfavourable phonetic position where it is realized as a partially devoiced fricative.

Preaspiration has not been proven to be a systematic "secondary" cue for Hungarian voiceless fricatives, and its use seems to instead be a speaker-specific contrast preservation strategy.

The question arises as to what role the observed phonetic features and their combinations play exactly in perception, and how the realizations falling in the overlapping regions can be distinguished, if at all.

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