A spectral analysis of the backing of Afrikaans /s/ in the consonant cluster /rs/

Otto Ewald
Center for Languages and Literature, Lund University, Sweden

Abstract

This acoustic study investigates the phoneme /s/ in Afrikaans and its backed realization in the consonant cluster /rs/ in coda position. The study focuses on spectral differences between the two contexts, with and without a preceding /r/, employing two spectral measurements: the center of gravity and skewness.

The analysis revealed a lower center of gravity and a lesser degree of skewness for /s/ in the cluster /rs/, indicating a flatter spectrum with more energy at lower frequencies, pointing at more back place of articulation and the realization of /s/ as a voiceless retracted alveolar sibilant [s̠] in this context. Future studies should aim at investigating additional acoustic properties of /s/ as well as /r/ in different contexts in Afrikaans to describe their exact realizations and their interaction in further detail.

Introduction

Sibilants feature a wide range of possible places of articulations and can further be described according to which part of the tongue comes in contact with the passive articulator during their production (Ladefoged and Maddieson, 1996). This gives rise to a large number of possible sibilant articulations, and earlier research has shown that the exact production of a sibilant phoneme (Dart, 1991) as well as its spectral characteristics (Hughes and Halle, 1956; Lindblad, 1980) can vary between speakers of the same language, although this might not be the case for all languages (Gordon et al., 2002). Furthermore, it has also been suggested that there is a tendency for greater articulatory variability in languages with a smaller set of sibilant phonemes such as English and French, than in those with a larger set, such as Mandarin Chinese and Swedish (Toda and Honda, 2006).

Acoustically, there are several cues to a sibilants place of articulation. As a general rule, the more front a sibilant's place of articulation is, the higher will the cut-off frequency be between low amplitude frequencies and high amplitude frequencies, which correlates with a decrease in size of the frontal cavity (Ladefoged and Maddieson, 1996; Lindblad, 1980).

Another acoustic measurement is the location of the frequency peak (Adam, 2012) or spectral peak frequency (Cheon and Anderson, 2008; Newman, 2003; Jongman et al., 2000), which has been found to be a good differentiator between for example /s/ and /ʃ/ in English.

Measurements that describe the whole spectrum have also been used to describe sibilants, such as the center of gravity and skewness. The former is a measure of the average frequency of the spectrum, while the latter indicates the asymmetry in the distribution of spectral energy in the frequency domain (Jongman et al., 2000).

Afrikaans, a West Germanic language spoken in South Africa, features an excellent opportunity to study sibilant allophony. /s/ is the only native phoneme, with /ʃ/ occurring as a foreign phoneme in a handful of loanwords such as *sjampanje* /ʃamˈpanjə/ 'champagne', *chirurg* /ʃiˈrœrx/, 'surgeon' (Donaldson, 1993), and *masjien* /maˈʃin/ 'machine'. Following Toda and Honda (2006), a larger allophonic variation in /s/ can be expected since the sibilant inventory is small, and Canepari and Cerini (2013) describe a range of phonetic realizations of /s/: dental, dentoalveolar, and alveolar. They note that alveolar realization is common in the consonant clusters /rs/, /sl/, /st/, and /sk/.

The backing of /s/ in the cluster /rs/ is deemed to be of particular interest here due to its similarity to the supradental realization of the cluster /rs/ as [ʂ] in western, northern, and central Swedish dialects (Bruce, 2010). This study explores Afrikaans /s/ in this particular rhotic context by comparing it to single /s/ in coda position, with the goal of identifying a backed allophone of /s/ in the /rs/ cluster and quantifying the acoustic differences in /s/ between the two contexts using the spectral measurements of the center of gravity and skewness. The backed allophone of /s/ after /r/ is expected to show more spectral energy at lower frequencies.

Experiment

Speakers

Three native speakers of Afrikaans were recorded, one male (M1) and two females (F1 and F2). They were 19-20 years old and currently studying in Bloemfontein at the time of the recording, but are originally from Vanderkloof (Northern Cape province), Bloemfontein (Free State province), and Schweizer-Reneke (North West province).

Material

The material consisted of a list of 20 words created specifically for this study and read in the carrier sentence *Ek het X geskryf* 'I wrote X'. The target words contained a coda /s/ in either a non-rhotic context (V_) or a rhotic context (Vr_) in the stressed syllable. The nucleus of the stressed syllable was one of the five vowels /a/, /ɛ/, /ɔ/, /i/, /u/ to minimize coarticulatory effects on the target phoneme. The test words are shown in Table 1. Each word occurred twice in the experiment, yielding a total of 40 words per speaker.

Table 1. Target words arranged according to vowel context and rhotic context.

	V_	Vr_
/a/	*vas* /ˈfas/	*vars* /ˈfars/
	kas /ˈkas/	*Mars* /ˈmars/
/ɛ/	*res* /ˈrɛs/	*kers* /ˈkɛrs/
	ses /ˈsɛs/	*pers* /ˈpɛrs/
/ɔ/	*los* /ˈlɔs/	*wors* /ˈvɔrs/
	kos /ˈkɔs/	*dors* /ˈdɔrs/
/i/	*kies* /ˈkis/	*passasiers* /pasaˈsirs/
	nies /ˈnis/	*Iers* /ˈirs/
/u/	*moes* /ˈmus/	*jaloers* /jaˈlurs/
	bloes /ˈblus/	*broers* /ˈbrurs/

Recordings

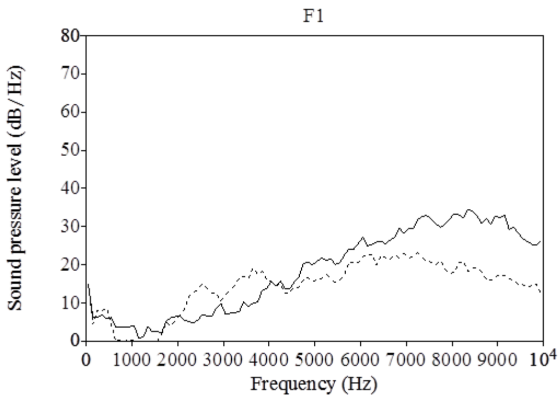
The three recordings were made in Audacity with a Triton Pro+ 5.1 True Surround Headset at a sampling rate of 44.1 kHz, and saved as 16 bit wav files. The male speaker was given instructions for the recording as well as the list with the 40 test sentences. He recorded himself with guidance from the author over Skype. He then assisted in carrying out the two subsequent recordings of the two female speakers F1 and F2.

Analysis

Analysis was carried out in Praat (Boersma and Weenink, 2013), and was based on FFT spectra running from 0 Hz to 10 kHz calculated from a 40 ms time window around the midpoint of the frication noise of each instance of /s/ to ensure maximal stability and representativeness of the fricative. The center of gravity and skewness of each FFT spectrum were calculated, and t-tests were carried out to find statistically significant differences in these two measurements between /s/ in the two contexts. Each FFT spectrum was also converted into a LTAS with a bandwidth of 100 Hz, and then averaged for each speaker and rhotic context for visual analysis.

Results

Spectra



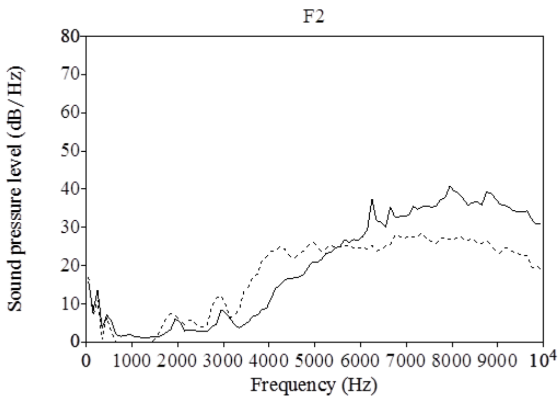


Figure 1. Average spectra for /s/ in the contexts V_ and Vr_ for F1 and F2. The V_ context is represented by a solid line and the Vr_ context by a dotted line.

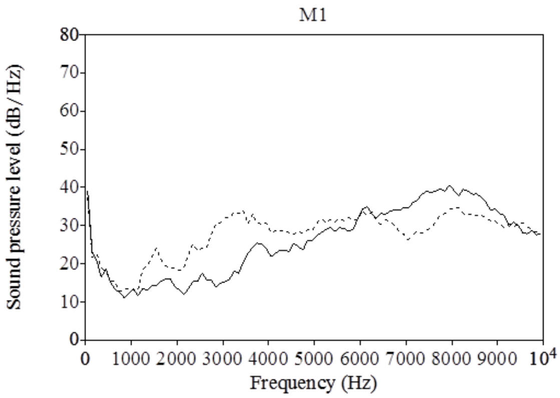


Figure 2. Average spectra for /s/ in the contexts V_ and Vr_ for M1. The V_ context is represented by a solid line and the Vr_ context by a dotted line.

The average spectra reveal a universal lowering in amplitude of higher frequencies in the Vr_ context compared to the V_ context for all speakers, as seen in Figure 1 and Figure 2. The frequency point above which this lowering takes place differs between speakers. The lowering takes place above 4400 Hz for F1, above 5500 Hz for F2, and between 6000 Hz and 9250 Hz for M1.

Each speaker also features a more varied amplification of some lower frequencies. F1 has two amplified spectral peaks centered around 2500 Hz and 3700 Hz respectively. F2 features a main amplification of frequencies between 3200 Hz and 5500 Hz, as well as two amplified peaks just below 2000 Hz and 3000 Hz. M1 has a broader band of frequency amplification between 1000 Hz and 6000 Hz.

F1 and F2 also display an additional lowering of low frequencies between 500 Hz and 1500 Hz.

Center of gravity

Table 2. The means and standard deviations for the center of gravity in the two contexts for each speaker.

	Mean (Hz)		Standard deviation (Hz)	
	V_	Vr_	V_	Vr_
F1	7847	6289	193	511
F2	8014	6852	424	440
M1	7199	5817	290	587

The center of gravity shows a considerable difference between the two contexts, as show by the mean values in Table 2 and the distribution of the data in Figure 3. /s/ in the Vr_ context features a more than 1100 Hz lower average than /s/ in the V_ context for all speakers, indicating more spectral energy at lower frequencies in the Vr_ context.

There is also a considerably larger variation in the Vr_ context, as show by the standard deviation in Table 2.

The difference in the center of gravity between the two contexts is highly significant for all speakers (p<0.01).

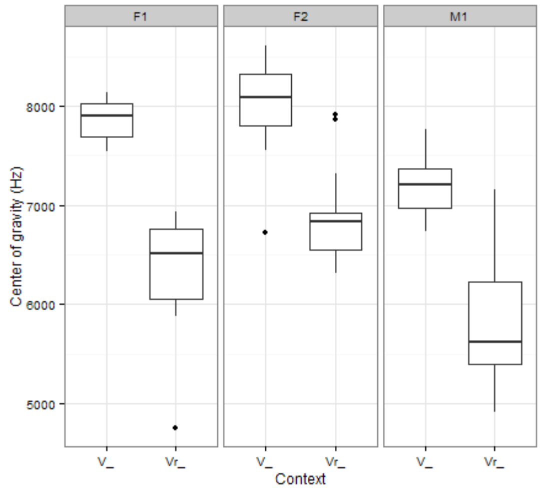


Figure 3. Box plot of the center of gravity in the two contexts for each speaker.

Skewness

Table 3. The means and standard deviations for skewness in the two contexts for each speaker.

	Mean		Standard deviation	
	V_	Vr_	V_	Vr_
F1	-1.2	-0.7	0.4	0.4
F2	-0.9	-0.6	0.8	0.4
M1	-2.5	-0.6	0.7	0.3

The differences in skewness are less clear compared to the center of gravity. Both contexts show overall negative skewness for all speakers, as can be seen in Figure 4. Although they all feature a lesser degree of skewness in the Vr_ context, the difference between the contexts is much smaller in F1 and F2 than in M1, as is evident in Table 3 and in Figure 4. The difference between the two contexts is here indicative of greater symmetry between the lower and higher frequencies of the spectrum, as Figure 1 and Figure 2.

As for standard deviation, F2 and M1 pattern together in having larger standard deviation in the V_ context, while there is no difference between the two contexts for F1 in this case.

However, while the difference in skewness is highly significant for F1 and M1 ($p<0.01$), it is not for F2 ($p=0.14$).

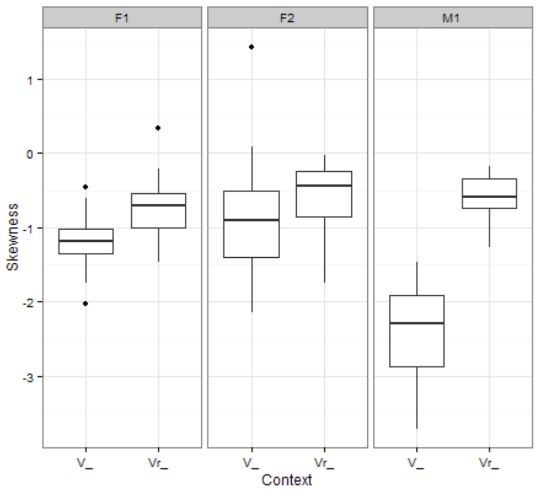


Figure 4. Box plot of skewness in the two contexts for each speaker.

Discussion

The backing of /s/

The results of the spectral analysis of /s/ reveal highly significant differences in the center of gravity for all three speakers as well as highly significant differences in skewness for F1 and M1 between the two contexts. These findings indicate a lowering in amplitude of high frequencies and more spectral energy at lower frequencies as well as a more equal distribution of spectral energy in /s/ when it is preceded by /r/, and it is possible to conclude that /s/ displays several acoustic signs of having a more back articulation in this context, strengthening Canepari and Cerini's (2013) observation and confirming the hypothesis.

The results also show parallels with Gordon et al. (2002) in that the center of gravity is a good measure of the place of articulation of a sibilant, while the measure of skewness on the other hand only gave statistically significant results for two of the speakers. This with the findings of Jongman et al. (2000), who consider skewness to be the best indicator of the place of articulation.

While it is clear that /s/ has a distinct allophone following /r/ with a more back place of articulation, it is difficult to precisely describe the articulatory setting from the results presented here, not only for /s/ in the Vr_ context but also in the V_ context. Based on Canepari and Cerini's (2013) description and the present results, the backed allophone of /s/ is tentatively labeled as a voiceless alveolar retracted sibilant [s̠].

Implications for further research

The results of the present study give rise to several new research questions to be answered in future research.

A more in-depth spectral analysis of /s/ in the two contexts should include other spectral measures such as kurtosis or could involve the measurement of the spectral peak in order to further describe the acoustic properties of this phoneme and its allophonic variation.

To increase our understanding of the interaction between /r/ and /s/ in the consonant cluster /rs/ in Afrikaans, it is imperative to also investigate the acoustic characteristics of /r/ in the V_ and Vr_ contexts, as well as other contexts, such as word-initially, word-medially, word-finally, and before other consonants such as plosives. While /r/ was not addressed in the present study, it seems to be rather weak in the /rs/ cluster, to the point where it is almost inaudible. /s/ itself should also be studied in the same different environments to better describe its allophonic behavior.

Going beyond acoustic phonetics, an articulatory study using electropalatography or articulography would be immensely helpful in describing the articulatory setting during the production of the allophones of /s/ in the two environments. It is however clear that such a study would be much more difficult to carry out with regards to the kind of equipment needed and the availability of participants.

The similarity between the described allophonic behavior of /s/ after /r/ in Afrikaans and the realization of the same cluster as a supradental [ʂ] in many Swedish dialects encourages cross-linguitic comparison between the sibilants in the two languages and might suggest, together with data on the behavior of /r/ in this context, that the /rs/ cluster in Afrikaans is going through the same change as its Swedish counterpart historically has done.

Conclusion

This study has explored the allophony of the /s/ phoneme in Afrikaans in two contexts, one without a preceding /r/ and one in the consonant cluster /rs/, employing the spectral measurements center of gravity and skewness. /s/ in the cluster /rs/ was found to have a lower center of gravity and a lesser degree of skewness, confirming the existence of a backed allophone of /s/ in this context, which has been tentatively described as a voiceless alveolar retracted sibilant [s̠].

Future research should aim at describing this retracted allophone of /s/ in further detail by using a greater range of acoustic measures and by studying it in different contexts. There is also a possibility for a cross-linguistic comparison between Swedish and Afrikaans when it comes to the consonant cluster /rs/ due to the similarity of its realization in the two languages, which might also be pointing at a sound change under way in Afrikaans.

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