# SPECTRAL MOMENTS ANALYSIS OF /s/ COARTICULATION DEVELOPMENT IN FINNISH-SPEAKING CHILDREN

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## ABSTRACT

In Finnish, coarticulatory effects of vowels readily appear in the production of the fricative /s/(S). In this developmental study, spectral moments analysis was used to compare young children's productions of S in symmetrical vowel (V) contexts (e.g. /iSi, uSu, ySy, ɑSɑ/) with similar adult productions. The subjects were children in three age groups while adult speakers served as control group.

Spectral moments were computed at 11 equidistant timepoints in the subjects' S tokens which were highpass-filtered at 700Hz. The results revealed that there were significant differences in the effects of vowel context on the acoustics of S between adults and children and also between the 3 groups of children. The findings suggest that there are salient developmental stages in children's progress toward adult-like phonetic realisations of S and that adult-like phonetic features of sibilants may appear in children's speech somewhat later than generally assumed.

**Keywords**: fricative production, coarticulation, spectral moments, 1st language acquisition.

## 1. INTRODUCTION

The Finnish fricative system only has the +coronal /s/ (S) and -coronal /h/ distinction. A system with a single coronal fricative phoneme allows for a fairly free emergence of coarticulatory effects in its phonetic realisations. In adult Finnish, these context-dependent allophonic variations such as labial-isation, result in perceivable differences in the quality of the noise component of S [10]. Previous research has also shown that vowel context has an effect on the spectral properties of /s/ [3].

Since early consonant productions by Finnish-speaking children have not been systematically investigated, there is also a gap in the data available for young children in the process of acquiring the phonetic features of S. Filling this gap in the data may have significant clinical applications, since S misarticulations are fairly frequent in Finnish-speaking children.

Since vowel context has been shown to be one of the most important determinants of the acoustic features of /s/ articulations [7,9], it is natural and worthwhile to make initial developmental observations on the variations of acoustic features of S in combinatorial sequences of S and vowels (V).

In acoustic analyses of fricative production, several alternative methods are available. Several recent acoustic studies of fricatives, e.g. [2,5,7,9], have relied on spectral moments analysis. It has been shown that at least some of the four spectral moments, i.e. the spectral center of gravity (M1), noise bandwidth or standard deviation (M2), skewness (M3) and kurtosis (M4), can be employed to differentiate and reveal certain variations in sibilant articulations [3,5,7] However, it has also been reported that spectral moments might not always reflect coarticulatory changes in fricative articulations [8]. In the present acoustic investigation of consonant production, spectral moments was selected as the method of analysis mainly because of its generally promising results in fricative analyses and in order to able to test whether previous findings by e.g. [3] suggesting that spectral moments do not reflect coarticulatory variations in place of articulation in sibilants fricatives can be reproduced in Finnish speech material..

The aims of the present acoustic investigation of consonant production are (i) to document a largely uninvestigated area in Finnish phonetics, i.e. the acoustic manifestations of allophonic variation of S and also (ii) to survey developmental phonetic features in 1st language acquisition in Finnish, i.e. normal (typical) acoustic features of children's S productions in different vowel contexts. For this purpose, adult speakers and children at three age levels below the assumed S production stabilisation at approx. 14 to years were selected as subjects.

Eventually, the findings of this investigation could also be used in building a reference acoustic database against which even children's atypical S articulations can be compared.

## 2. METHODS

The subjects of this study were ten young native speakers of Finnish in 3 age groups, hereafter referred to as “6 yrs”, “9 yrs” and “11 yrs” (mean ages 6.3, 9.3 and 10.7 years, respectively) and 10 adult controls (mean age 22.4 years). The subjects, representing both sexes, produced 5 S tokens in 5 symmetrical vowel contexts; the vowel context of S was varied symmetrically by lip articulation (round /ySy uSu/ vs. unround /iSi æSæ ɑSɑ/), tongue height (high /iSi ySy uSu/ vs. low /æSæ ɑSɑ/) and backness (front /iSi ySy æSæ/ vs. back /ɑSɑ uSu/). The context was controlled by using disyllabics with word-initial S which were imbedded in carrier phrases so that S was preceeded and followed by the same vowel (e.g. / nyt vuot**ɑɑ Sɑɑ**vi / and / nyt riitt**ææ Sææ**li /).

TF32 [6] was used to compute the spectral center of gravity, i.e. moment 1 or M1 (kHz) and noise bandwith, i.e. moment 2 or M2 (kHz) (see e.g. [8]), at the S onset and offset and at 9 equidistant time points between onset and offset. In other words, M1 and M2 values in each of the S tokens were computed at 11 time points with approx. 10 to 15 msec intervals allowing for the variation in S token durations. (Spectral moments 3 and 4 were also computed but are not reported here.)

## 3. DATA AND RESULTS

The results from acoustic analyses showed that the effects of vowel context on the noise characteristics of S were at their most systematic at the timepoints corresponding to the temporal midpart of the fricative, i.e. between timepoints #3 and #8 corresponding to the interval from 30 per cent to 80 per cent of the total duration of the S tokens.

Thus, mean values (with 95% CI) for the spectral moments M1 and M2 were computed at timepoints #3 thru #8 in the temporal mid-part of the S tokens (Tables 1 and 2). Comparison of means revealed that there were statistically significant (p=.000) differences in the M1 and M2 values between adult speakers and children and also between the 11 yrs, 9 yrs and 6 yrs groups. This result differs from the findings reported in [11] where age was not found to have an effect on the center of gravity frequency of /s/.

**Table 1**: Mean center of gravity frequencies (M1) of the S spectra in the 5 vowel contexts for the 3 groups of children and adult controls.

| M1 (kHz) | vowel context | | | | |
|---|---|---|---|---|---|
| | /si/ | /sy/ | /su/ | /sæ/ | /sɑ/ |
| adult | 8.637 | 8.331 | 7.509 | 8.250 | 8.189 |
| 11 yrs | 7.484 | 7.178 | 7.125 | 6.932 | 7.133 |
| 9 yrs | 7.343 | 7.335 | 6.869 | 6.907 | 6.676 |
| 6 yrs | 8.284 | 7.893 | 7.177 | 7.422 | 6.643 |

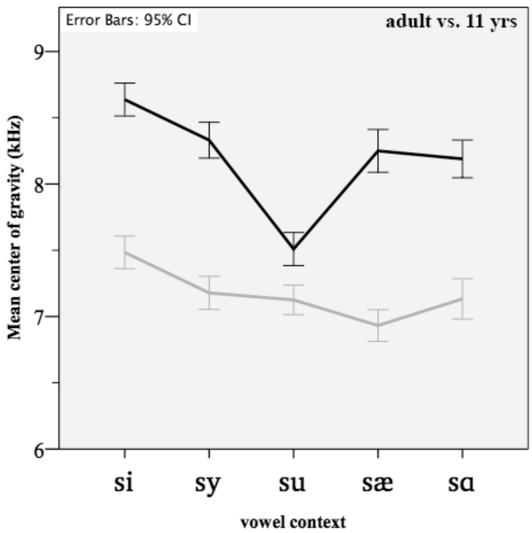
Differences in the M1 and M2 data between female and male speakers in all speaker categories were statistically significant (p=.000) with mean absolute values of female speakers‘ M1 being slightly higher. This result is in line with findings in [4].

**Table 2**: Mean noise bandwidth values of the S spectra in the 5 vowel contexts for the 3 groups of children and adult controls.

| M2 (kHz) | vowel context | | | | |
|---|---|---|---|---|---|
| | /si/ | /sy/ | /su/ | /sæ/ | /sɑ/ |
| adult | 1.926 | 1.794 | 1.722 | 1.703 | 1.876 |
| 11 yrs | 2.513 | 2.464 | 2.624 | 2.589 | 2.693 |
| 9 yrs | 2.243 | 2.079 | 2.254 | 2.214 | 2.132 |
| 6 yrs | 2.472 | 2.513 | 2.361 | 2.609 | 2.471 |

One-way ANOVA with Dunnett t and Dunnett’s T3 *post hoc* analyses were used to evaluate the effects of vowel context on the two spectral moments variables of S.

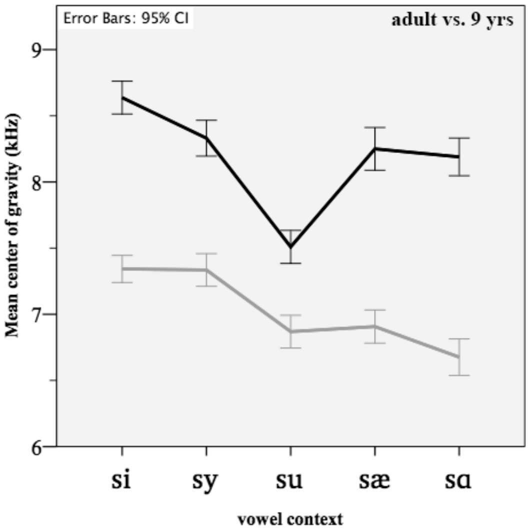
**Figure 1**: The effect of vowel context on the mean center of gravity frequency (in kHz) of the S fricative noise. Adult controls (black line) vs. children at 11 yrs (grey line).




The general effect of vowel context on M1 was statistically significant (p=.000) in all speaker groups. In the adult data, the highest and lowest M1 frequencies were observed in the /i/ and /u/ contexts (Table 1, black line in Figures 1 thru 3), respectively, and compared with the /i/ context, the /y/, /u/, /æ/ and even /ɑ/ contexts displayed a statistically significant (p=.000) lowering effect on the center of gravity frequency.

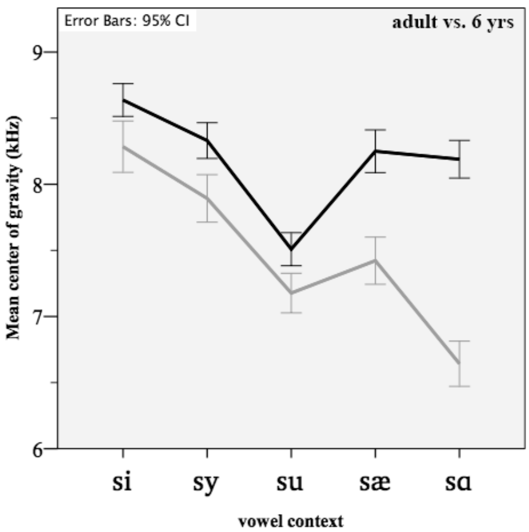
In the data for the 11 and 9 year-olds (grey line in Figure 1 and Figure 2, respectively), the pattern of changes in M1 frequency due to vowel context variation deviated from the adult model pattern and the mean differences in M1 between the 5 vowel contexts were smaller and statistically non-significant except for the /i/ vs. /u/ and /æ/ contexts.

**Figure 2**: The effect of vowel context on the mean center of gravity frequency (in kHz) of the S fricative noise. Adult controls (black line) vs. children at 9 yrs (grey line).



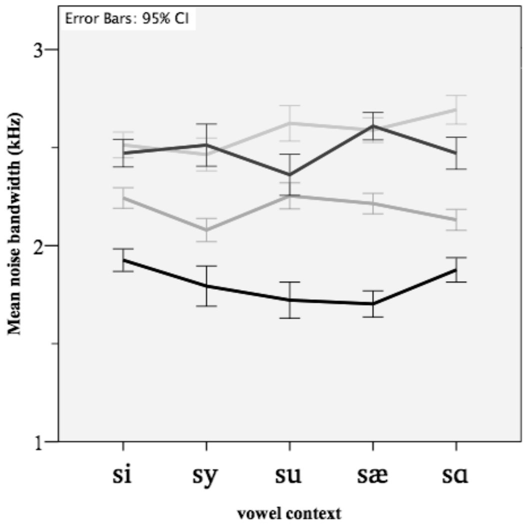

In the data for the 6 year-olds, the pattern of changes in M1 frequency due to vowel context variation (grey line in Figure 3) resembled the adult model pattern with an even more pronounced and statistically significant decrease in M1 frequency in the /æ/ vs. /ɑ/ contexts compared with the adult model.

**Figure 3**: The effect of vowel context on the mean center of gravity frequency (in kHz) of the S fricative noise. Adult controls (black line) vs. children at 6 yrs (grey line).




The differences in the mean M2 values in the /u/ and /y/ contexts were significantly lower compared with the /i/ context in the adult data. The M2 data for the children displayed different patterns of changes (see Figure 4) and mainly non-significant differences due to vowel context variation, except for the /u/ context, which caused a significant decrease in M2 in the 6 year-old group. The results for M2 in the /i/ vs. /y and /u/ context in this study do not correspond to the results reported in [4] where it was found that the noise bandwidth of /s/ is slightly wider in the context of round vowels .

**Figure 4**: The effect of vowel context on the mean noise bandwidth (in kHz) of the S fricative. Adult controls (bottom line) vs. children at 11 yrs (top grey line), 9 yrs (bottom grey line) and 6 yrs (top black line).




## 4. CONCLUSIONS

The results of the present acoustic study, partly in line with and partly different from previous studies such as [4,7] indicate that while adult speakers' S exhibits significant effects of vowel coarticulation in its spectral features, especially in the M1 frequency, children at ages 6 and 9 and also 11 are still in the process of acquiring adult-like phonetic features for S articulation, even in symmetrical vowel contexts. Not all previous studies [11,9] support the general finding of this investigation, namely that there are significant age-related spectral differences in children's /s/ productions.

One of the most unexpected results of the present study was that in the children's articulations, the pattern of changes in M1 of the S of the 11-year-olds bears the least resemblance to the adult pattern. The results for the 6-year-old pre-school children, which exhibit a slightly more adult-like pattern of changes (see Figure 3) compared with the older groups, especially in high vowel contexts, i.e. /si sy su/, may reflect an increased awareness of allophonic S variations but also carefully articulated vowel contrasts. Compared with the adult pattern of changes, the 6 year-olds seem to "overcoarticulate" S in the context of low back and front vowels, i.e. /sɑ/ vs. /sæ/.

It is possible that the differences in the children's results can be partly attributed to differences in their vowel articulation. Obviously, coarticulation studies such as this have to be extended to cover even the acoustics of vowel articulation, especially at ages below the assumed articulation stabilisation.

In general, the present results support inferences about a gradual emergence – partly dependent on motor skills – of adult-like speech patterns in children's speech [7]. Because of the rather small number of subjects in each speaker group, the results of the present study need to be further substantiated by a larger number of speakers and also at ages closer to the age of assumed S production stabilisation.

One of the motives for the present study was to start filling a gap in the data available for children acquiring the phonetic features of Finnish consonants; the present results – although only preliminary in nature – can be regarded as a beginning in building a reference database against which adults' and children's consonant articulations can be compared.

## 5. REFERENCES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