



# How sibilant spectra shape gender perception in prepubertal children: A voice morphing study

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## Abstract

Spectral characteristics of sibilants have been linked to social factors such as gender or sexual orientation. This paper examines the impact of sibilant spectra on gender perception in prepubertal German-speaking children (ages 6–9) through a longitudinal study. Center of Gravity (CoG) and skewness were measured in the sibilant /z/. Two listening experiments assessed gender perception: one with natural stimuli, the other with voice morphed stimuli to isolate the effect of sibilant spectra.

No overall gender differences in CoG and skewness were found. While sibilant spectra had no effect on gender perception in natural stimuli, significant effects emerged in morphed stimuli. This suggests that while broader acoustic cues may have a stronger effect on gender perception, sibilants also reflect stereotypical gender associations in isolation.

**Index Terms:** prepubertal voices, gender perception, sibilant spectra, voice morphing

## 1. Introduction

Recent sociophonetic research on the production of sibilants like /s/ and /z/ has highlighted the significant role of social factors in shaping their acoustic characteristics [1].

Although physiological differences – such as the geometry of the oral cavity, tongue position, constriction size, and lip configuration – may partially explain the variation observed between male and female speakers [2], social and behavioral factors appear to play a more significant role.

Research indicates that speakers actively adjust their articulation to align with specific social identities. In this context, higher frequency sibilants with a diffuse spectrum, can be associated with femininity, while lower frequency sibilants are often associated with masculinity [3].

Studies on children’s speech further illustrate the significant impact of social and cultural factors on phonetic variation. Although prepubescent children exhibit minimal sexual dimorphism in vocal tract anatomy [4], clear gender differences in sibilant production are still observed. For example, [2] and [5] report that English speaking girls produce sibilants with higher values of Center of Gravity (CoG) and display more negative skewness values compared to boys, reflecting a higher concentration of fricative energy in higher frequency ranges. Similar patterns have also been observed in adult speakers [1].

A comprehensive study by [6] highlights gender identity as a key factor shaping differences in sibilant production among Canadian children aged four to 16 years. Consistent with previous research, girls exhibit higher CoG values and more negative skewness values. These differences become increasingly pronounced with age. Gender identity exerts a significant influence

on the production of sibilants, with a particularly strong correlation observed between skewness and gender identity values in boys.

While previous studies have either explored the influence of gender on the production of sibilants or investigated how acoustic parameters of sibilants affect gender perception in children, this study aims to integrate both production and perception. For this purpose, recordings from the longitudinal German LoKiS corpus were analyzed [7].

The corpus features stimuli from approximately 60 prepubertal children aged six to nine years. We measured CoG and skewness of the sibilant /z/ from repeated sentences spoken by each child at three different time points. Additionally, we carried out a gender perception experiment (listening experiment 1) to explore how CoG and skewness influence gender perception in natural stimuli. Furthermore, we conducted an innovative voice-morphing experiment (listening experiment 2) to specifically isolate the effect of sibilant spectra on gender perception while controlling for other acoustic parameters. Our specific research aims are as follows:

1. Examine differences in CoG and skewness of /z/ between prepubertal children assigned female at birth (AFAB) and assigned male at birth (AMAB) and between unambiguous feminine- and masculine-sounding children.
2. Investigate how sibilant spectra influence gender perception in natural stimuli.
3. Evaluate how sibilant spectra influence gender perception in synthetic stimuli generated through voice morphing.

This study is important as it offers insights of how individual acoustic parameters, specifically sibilant spectra, contribute to the perception of gender. By focusing on prepubertal children, it highlights the influence of social and behavioral factors on phonetic variation, and by investigating German, it expands the literature on languages other than English, advancing our understanding of the social dimensions of speech.

## 2. Method

### 2.1. Speakers

Acoustic recordings were made of 62 children (29 girls, 33 boys) aged 6–7 years ( $M = 6.16$ ,  $SD = 0.37$ ) in 2020 at two primary schools in East Germany.

All children were monolingual native German speakers and their parents provided consent. A follow-up recording took place in 2021 with 60 of the 62 children (28 girls, 32 boys) aged 7–8 years ( $M = 7.18$ ,  $SD = 0.39$ ), and a third recording was made in 2022 with 56 of the 62 children (26 girls, 30 boys) aged 8–9 years ( $M = 8.16$ ,  $SD = 0.37$ ) (for more details of the speakers in the LoKiS corpus, see [7]).

## 2.2. Audio recordings

A full list of the recorded speech material in the LoKiS corpus can be found in [8]. The children were recorded individually in a quiet room at school, with background noise rarely interfering. Both spontaneous and controlled speech were elicited, including a picture-naming task and repetitions of ten different sentences. Recordings were made using a USB microphone in a portable sound shield, ensuring minimal intrusion and noise. Recordings were made using Audacity [9] with 32-bit amplitude resolution and a sampling rate of 44.1 kHz.

In the present study, acoustic analysis and stimuli for the listening experiments are restricted to the repetitions of the sentence: “Im Sommer blühen die Blumen.” (“Flowers blossom in summer.”). As with all sentences in the recording list, this sentence was pre-recorded by an adult female speaker. The children repeated the sentence after hearing the adult version. We recognize that this approach may lead children to imitate aspects of the adult speaker’s voice beyond the verbal content. However, given the limited literacy skills of first-graders, it was the most practical way to elicit consistent, sentence-length utterances. Using identical pre-recorded stimuli for all participants and time points helped to minimize potential interferences.

## 2.3. Acoustic analysis

To analyze gender differences in sibilant spectra (research aim 1), the recordings of the children were segmented and annotated using WebMAUS [10]. The praat [11] text grids were then manually checked and corrected. All acoustic analyses were also performed in praat [11]. CoG and skewness were measured in the sibilant /z/ of “Sommer” (Summer) in the sentence “Im Sommer blühen die Blumen” (“Flowers blossom in summer”).

In the calculation, we used a praat script which calculates spectral features from the /z/ sound by generating a spectrum and analyzing its frequency properties. From this spectrum, it computes CoG (which measures the balance point of the frequency distribution) and skewness (to assess the asymmetry of the frequency distribution) using built-in functions for spectral analysis. Prior to this, the signal was resampled to 22.05 kHz and processed with a Hann bandpass filter (200 Hz to 11.025 kHz) to remove unwanted frequency components. Both CoG and skewness were measured across the entire sibilant to retain maximal signal information. The 200 Hz cutoff was chosen as a conservative compromise to attenuate low-frequency noise without substantially affecting the voiced sibilant signal.

## 2.4. Listening experiment 1 – Gender perception

The purpose of listening experiment 1 was to evaluate how feminine or masculine the children’s voices were perceived to be. The stimuli included recordings of two sentences and a spontaneous picture description. In this study, we concentrate on the results of the sentence “Im Sommer blühen die Blumen” (“Flowers blossom in summer”), as the sibilant spectrum (/z/ in “Sommer”) aligns with research aim 2 of investigating how natural stimuli influence gender perception.

The listening experiments were carried out online via Percy [12], with individual experiments conducted for recordings from first, second, and third graders. Stimuli were played in random order. Listeners decided on a seven-point scale whether they had heard a ‘boy’ or a ‘girl’ on a scale from 1 (definitely a boy) to 7 (definitely a girl). We used the same anchor terms ‘boy’ and ‘girl’ as in previous studies [13, 14]. We relied on the assumption that listeners would choose ‘boy’ when they clearly

perceive the child as masculine and ‘girl’ if they clearly perceive the child as feminine.

A total of 167 listeners participated in the first-grade experiment (119 female, 46 male, 2 diverse, age: 18-71,  $M = 33.2$ ,  $SD = 13.7$ ). For the second grade, 114 listeners took part (94 female, 18 male, 2 diverse, age: 18-70,  $M = 33.2$ ,  $SD = 13.4$ ). The third-grade experiment included 101 listeners (77 female, 20 male, 4 diverse, age: 18-77,  $M = 33.6$ ,  $SD = 14.5$ ). None of the participants reported hearing problems, and the majority were native German speakers. To reduce the duration of the experiment, the stimuli were divided among three groups of listeners in each experimental session, with the groups and the number of stimuli being approximately equal in size.

## 2.5. Listening experiment 2 – Voice morphing

The aim of listening experiment 2 was to examine the isolated effect of sibilant spectra on gender perception while keeping other acoustic parameters constant (research aim 3). Stimuli were created using TANDEM-STRAIGHT [15], a tool for flexible speech signal manipulation. Each speech signal was decomposed into source-related parameters and a spectral envelope. The decomposition process segmented speech into time and frequency anchors, ensuring precise morphing between corresponding acoustic segments. Time anchors were positioned at significant acoustic transitions. Two frequency anchors provided control over the spectral peak of /z/ in “Sommer”.

The dataset comprised recordings of the sentence “Im Sommer blühen die Blumen” (“Flowers blossom in summer”) from five AFAB and AMAB children (third grade). The children were selected based on their extreme gender perception ratings (see experiment 1) and the largest differences in CoG and skewness. Morphs were created between every pair of a feminine-sounding AFAB and a masculine-sounding AMAB child.

For each of the 25 possible pairs between the five AFAB and five AMAB children, the spectral peak of the sibilant /z/ was morphed independently in 20% steps, from 0% (parameters of the feminine voice) to 100% (parameters of the masculine voice). Other parameters, including the spectral envelope and aperiodicity, were kept at 50% (mathematically halfway between the two voices). This procedure yielded 150 individual stimuli (5 AFAB  $\times$  5 AMAB  $\times$  6 morphing steps).

123 listeners took part in listening experiment 2 (103 female, 16 male, 4 diverse, age: 18-70,  $M = 30.1$ ,  $SD = 10.7$ ). Most participants were native German speakers, and none reported any hearing impairments.

Similar to listening experiment 1, listening experiment 2 was conducted online using Percy software [12], following the same procedure. Participants rated each stimulus on a seven-point scale, indicating whether they perceived the voice of a ‘boy’ (value 1) or a ‘girl’ (value 7). To shorten the experiment’s duration, the 150 stimuli were divided into three approximately equal sets, each presented to a separate group of listeners, with the stimuli and listeners evenly distributed across the groups.

## 2.6. Data analysis

Statistical analyses were run in R [16]. Graphical analyses were made using the ggplot2 package [17].

To examine the effect of gender on CoG and skewness (research aim 1), we conducted linear mixed models (LMMs) with the lme4 package [18]. Separate models were calculated with CoG and skewness as the dependent variables and gender as a fixed factor. We also tested for interactions with grade level. A random intercept was included for each child to account for in-

dividual variability. P-values were calculated using likelihood ratio tests, comparing models with and without the inclusion of gender. Potential effects and interactions were visualized using the `ggeffects` [19], `sjPlot` [20], and `sjmisc` [21] packages. Post hoc group comparisons were conducted with Tukey tests using the `emmeans` package [22].

We also performed two-sample independent t-tests to compare AMAB and AFAB children. When the Shapiro-Wilk test indicated a deviation from normality, Wilcoxon rank-sum tests were used instead. Effect sizes were calculated for all comparisons. Additionally, we analyzed the five most feminine- and masculine-sounding children from listening experiment 1 in each grade to determine whether these extreme groups exhibited greater differences compared to the overall differences between AMAB and AFAB children. For this analysis, a mean gender perception index was calculated for each child based on the results of listening experiment 1.

The influence of sibilant spectra on gender perception in natural stimuli (research aim 2) was analyzed using LMMs, following the same procedure as described above. Separate models assessed the effects of CoG and skewness (fixed factors) on the mean gender perception index of listening experiment 1 (dependent variable), including interactions with speaker gender (AFAB vs. AMAB) and grade level (grades 1, 2, and 3). Speaker was modeled as random intercept.

To investigate how sibilant spectra influence gender perception while controlling for other acoustic parameters (research aim 3), data from listening experiment 2 (voice morphing) were analyzed using LMMs with the same methodology. For this evaluation, a gender perception index was calculated for each child based on the results of listening experiment 2 and used as the dependent variable. Morphing steps (ranging from 0–100% in 20% steps) were treated as the fixed factor, while morph (stimulus) and listener were included as random intercepts.

## 3. Results

### 3.1. Gender differences in /z/

The LMMs, using the values of the sibilant spectra in /z/ as the dependent variables and gender as a fixed factor, reveal no significant gender differences. The children’s gender shows no measurable effect on either CoG ( $\chi^2(1) = 1.48, p = .22$ ) or skewness ( $\chi^2(1) = 1.23, p = .27$ ) and no effect with grade level can be found.

As shown in Table 1 and illustrated in Figure 1, the results of the two-sample independent t-test and Wilcoxon rank-sum tests comparing gender differences between AMAB and AFAB children indicate no significant differences in CoG or skewness. However, in both first and third grade, CoG values are slightly higher, and skewness values slightly lower in AFAB children.

When comparing the five most feminine- and masculine-sounding children from listening experiment 1, the feminine group exhibit higher CoG values in first and third grade. Additionally, skewness is lower in the feminine group in both first and third grade. However, in the second grade, a reversed trend can be observed, with lower CoG values and higher skewness values in the feminine group.

### 3.2. Gender perception in natural stimuli

In listening experiment 1, listeners rated each child’s repetition of the sentence “Im Sommer blühen die Blumen” (“Flowers blossom in summer”) on a seven-point scale, ranging from 1 (‘boy’) to 7 (‘girl’). Based on these ratings, we calculated a

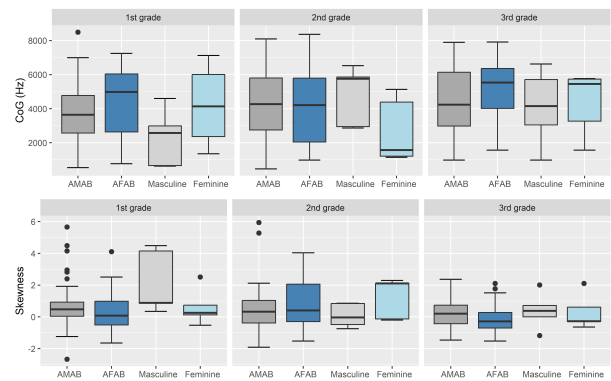


Figure 1: Differences in CoG (above) and skewness (below) of /z/ between AMAB and AFAB children and unambiguous feminine- and masculine-sounding children, separated by grade level.

mean gender perception index for each child at each of the three time points.

The LMMs with the gender perception index as the dependent variable and CoG and skewness as fixed factors reveal no significant effects. Neither CoG ( $\chi^2(1) = 1.24, p = .27$ ) nor skewness ( $\chi^2(1) = 1.27, p = .26$ ) shows any influence on the gender perception index in the natural stimuli.

### 3.3. Gender perception in voice morphing stimuli

In listening experiment 2, listeners evaluated 150 voice-morphed stimuli, consisting of 25 morphing pairs with 20% morphing steps in the sibilant spectrum of /z/ in the sentence “Im Sommer blühen die Blumen” (“Flowers blossom in summer”). Ratings were given on a seven-point scale from 1 (‘boy’) to 7 (‘girl’).

A LMM was performed with the gender perception values as the dependent variable and morphing step (20%, 40%, 60%, 80% and 100%) as the fixed factor. In contrast to natural stimuli, the sibilant spectrum of the voice-morphed stimuli shows a significant effect on gender perception ( $\chi^2(5) = 407.56, p < .0001$ ).

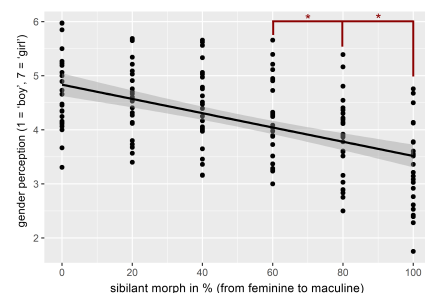


Figure 2: Relationship between gender perception (1 = ‘boy’, 7 = ‘girl’) and morphing step from feminine to masculine sibilant spectrum. Significant differences \* ( $p < .05$ , with Bonferroni-Holm correction) in red.

Summarized in table 2 and illustrated in figure 2, the Post-hoc-Tukey-Tests reveal a significant decrease in the gender perception values between 60% to 80% morphing steps, as well as

Table 1: Means, standard deviations and results of the statistical tests comparing gender differences in CoG and skewness of /z/ between AMAB and AFAB children (left) and unambiguous feminine- and masculine-sounding children (right) separated by grade level. P-values Bonferroni-Holm corrected.

CoG (Hz)														
Grade	AMAB		AFAB					Masculine		Feminine				
	M	SD	M	SD	t/W	p	d	M	SD	M	SD	t/W	p	d
1st	3623	1998	4307	2036	1.58	.11	.41	2289	1683	4197	2414	-1.45	.19	.92
2nd	4247	1998	4129	2236	-0.21	.83	.06	4719	1743	2688	1916	1.81	.11	1.2
3rd	4411	1858	5093	1819	1.39	.18	.37	4100	2224	4356	1873	-0.20	.85	.12

Skewness														
Grade	AMAB		AFAB					Masculine		Feminine				
	M	SD	M	SD	t/W	p	d	M	SD	M	SD	t/W	p	d
1st	0.91	1.69	0.45	1.24	344	.09	.22	2.15	2.00	0.62	1.15	21.0	.10	.53
2nd	0.53	1.64	0.73	1.41	476	.52	.08	0.09	0.74	1.24	1.28	-1.74	.12	1.1
3rd	0.25	0.92	-0.11	0.94	-1.43	.16	.39	0.38	1.16	0.30	1.11	0.12	.91	.07

Table 2: Post-hoc-Tukey-Tests: Effect of morphing step on gender perception (1 = boy, 7 = girl). \* = Significant differences ( $p < .05$ , with Bonferroni-Holm correction).

Sibilant (feminine to masculine)				
Morphing step	M	SD	Difference	p
0 %	4.67	0.15	-	-
0 % vs. 20 %	4.56	0.15	0.11	.73
20 % vs. 40 %	4.40	0.15	0.16	.58
40 % vs. 60 %	4.22	0.15	0.19	.45
60 % vs. 80 %	3.83	0.15	0.39	.0001*
80 % vs. 100 %	3.34	0.15	0.49	.0001*

between 80% to 100%. This demonstrates that shifting the sibilant spectrum in just one sound of the whole sentence (/z/ in the word ‘Sommer’) by 20% from the feminine to the masculine pattern is sufficient to induce a significant change in gender perception. Stimuli are perceived as significantly more masculine when the sibilant spectrum becomes only 20% more masculine, starting from a shift of 60%.

## 4. Discussion

In research aim 1, we examined gender differences in CoG and skewness of /z/ between AFAB and AMAB children, as well as between unambiguous feminine- and masculine-sounding children. No significant gender effects were found, but AFAB children and feminine-sounding children show higher CoG values and more negative skewness values in first and third grade. These results align with previous studies [2], [5], [6] and suggest that higher CoG and lower, more negative skewness values could be associated with femininity in prepubertal voices. However, in second grade, an inverse trend was observed, with higher CoG values and lower, more negative skewness values in the masculine-sounding group. This could be explained by the fact that different children were perceived as particularly feminine or masculine in each grade. Therefore, the production of /z/ could be more speaker- than gender-specific, which is also reflected in the high within-group standard deviations.

While trends for higher CoG and lower skewness values in feminine-sounding children are apparent, they are not statistically significant, suggesting that gender differences in sibilant spectra may not yet be fully established in children this young. Further investigation is needed to explore how these patterns develop with age.

Research aim 2 investigated the effect of sibilant spectra on gender perception in natural stimuli, but no significant effect was found. This may be due to the lack of significant differences in CoG and skewness between AFAB and AMAB children, as well as the potential influence of more global acoustic parameters on gender perception, such as fundamental frequency [7].

In contrast, the results of research aim 3, which focused on synthetic stimuli generated via voice morphing, show that a 20% shift from feminine to masculine in a single sibilant significantly changes gender perception. This suggests that sibilants play an important role in shaping gender perception in prepubertal children when other acoustic parameters are controlled.

Overall, while young children may not yet reliably differentiate gender based on sibilant spectra in natural speech, sibilants appear to be one key factor systematically used by adult listeners in the perception of gender in prepubertal voices.

### 4.1. Limitations

Our results are based on German children and listeners, so we refrain from generalizing to other languages. Perceptions may differ across languages or among listeners with different native languages [23]. In the listening experiments, we used a 7-point scale with ‘boy’ and ‘girl’ anchors to assess gender perception, ensuring consistency with previous studies like [14] or [23]. Although terms like ‘masculine/feminine’ could have been used, they may lead to variable interpretations, with some listeners focusing on gender while others might assess aspects beyond the initial gender perception. In listening experiment 2, we used voice-morphed stimuli. While a few listeners noted slight audio quality issues, the robust findings suggest minimal impact on gender judgments. Furthermore, we focused only on /z/ in one context. Despite multiple tokens per child, manual processing and splitting across listeners made this compromise necessary.

### 4.2. Further steps

Future steps include collecting additional recordings from the same children to track acoustic changes during the onset of puberty. This will offer valuable insights into intraspeaker changes in transpubertal gender and voice. Additionally, we aim to explore the influence of a child’s gender role self-concept on acoustic parameters like sibilant spectra, similar to [6]. To achieve this, we collect self-reported data on gender conformity from each child at all time points using an age-appropriate questionnaire.

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