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Original Article

Acoustic Properties of Turkish Sibilants in Cleft Palate Speech

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ABSTRACT

Objective: Cleft lip and palate is one of the most common birth defects. It may result in anatomical differences, feeding, dental, hearing, and speech problems. Many speech problems occur due to insufficient velopharyngeal closure, and this causes inappropriate air leakage to the nasal cavity resulting in hypernasality. In such speech, the obstruent sounds are weakened or distorted. The aim of this study is to analyze the acoustic properties of Turkish fricatives of children with cleft lip and palate having hypernasality.

Methods: For this purpose, duration, voicing duration, center of gravity (M1), skewness (L3), and kurtosis (L4) values of sibilants (/s, z, ʃ, ʒ/) were measured. Each sibilant was located word-initial position within a sentence. Four children with cleft palate with hypernasality and 4 children without cleft palate participated in the study. All the participants were Turkish native speakers, and their age range was 10-12. The data was analyzed with R and linear mixed model.

Results: It has been seen that the duration of target sounds is longer for children with cleft palate having hypernasality. Moreover, M1 is found lower for these participants than those without hypernasality. Although L3 does not show any discrepancy for both groups, L4 is lower for the children with cleft palate having hypernasality.

Conclusion: It has been found that hypernasality affects the duration, M1 and L4 of target sibilant sounds. All results have shown that children with hypernasality need more time and prefer back articulation to create the intra-oral pressure; however, they canno create enough turbulence required for fricatives.

Keywords: Hypernasality, cleft lip and palate, fricatives, spectral moments, acoustics.

Introduction

Cleft lip and palate (CLP), the fourth most common congenital disorder among congenital anomalies, causes several problems such as feeding, speech, resonance, orthodontic, social, and psychological.[1] The surgeries of individuals with cleft palate are performed at early ages (cleft lip at the age of 3 months and cleft palate at 9-12 months[1]) however, despite multidisciplinary teamwork, advanced surgical techniques, and speech therapy, hypernasality can be observed in 20-30% of children due to velopharyngeal insufficiency (VPI).[2] This affects the production of speech sounds. Even if the place of articulation and the voicing features are correct, the manner of articulation cannot be formed as desired due to nasal leakage.

The speech problems related to cleft palate can be characterized by articulation errors, phonological disorders, and abnormal resonance such as hypernasality, hyponasality, and nasal emission.[3] Obstruent sounds (fricatives, stops, and affricates) that require high intra-oral pressure are the most vulnerable sounds in cleft palate speech.[1,4,5,6,7] Sibilants and the sound /s/ are distorted in the presence of VPI.[4,5]

In this study, the effect of hypernasality on the acoustic properties of sibilant sounds was investigated. In the following section, the acoustic properties of sibilant sounds as well as the effect of VPI on those sounds is explained.

1 The timing of the surgery can change due to the surgeon, country, or additional health problems.

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Acoustics of Sibilant Sounds and Effect of VPI

Many studies have been conducted to explain the acoustic properties of fricatives so far. In some of these studies, amplitude, frequency, duration of fricative noise, fricative-vowel formant transitions, and ERBn (a psychoacoustic measure of peak frequency) have been analyzed to identify the fricatives.[8-12]

Although fricative noise and duration provide precious information about the fricatives' articulatory and acoustic properties, frequency alone may not provide enough information about spectral shape in fricatives. In addition to frequency, the shape of the spectrum and the frequency distribution can be described by means of spectral moments.[13] Spectral moment analyses (SMA), a common technique developed by Forrest et al.[14] involves a series of statistical procedures that address local (center of gravity) and global (spectral slope and peak) aspects of speech sounds for the classification of obstruents. In many studies, SMA has been used to describe the fricatives acoustically in English and other languages.[8,9,13,15-21,]

The utilization of SMA for exploring consonants is engaging for 2 reasons. First, it gives quantitative data around aperiodic noise spectra of fricatives that can be utilized to report clinically remarkable alteration. Second, SMA can help point out the degree of categorical distinction in the production of consonants that may or may not be discernible to the ear. Thus, it provides a basis for comparison between normal and disordered speech. SMA also gives a chance to differentiate sibilants from non-sibilants and the sibilants from one another.[22]

In SMA, the first 4 moments are analyzed to classify obstruents based on their place of articulation. The first moment, Center of Gravity (M1, COG), represents the average energy of all frequency. Standard Deviation (M2, SD), indicates the range of the energy spectrum. The third moment (L3, skewness) reflects the symmetry of the distribution, the fourth moment (L4, kurtosis) highlights the peakedness of the distribution. By considering these different spectral properties, obstruents can be distinguished from each other using SMA.[8,10]

In some studies, 2 or more spectral moments have been combined to achieve a more complete characterization of the spectrum, and this has resulted in satisfactory differentiation between the sibilant fricatives, particularly when both the spectral mean and the spectral skewness are included.[17]

Acoustic analysis of disordered speech is quite rare in speech therapy practice. Mostly, clinicians rely on their perceptual analysis although those methods are available at low cost. The reason why they are avoided might be found in the explanation of Kent and Kim.[23] According to these authors, the following are necessary for successful acoustic analysis in speech impairment: (i) normative data, (ii) potential pitfalls in using these methods, (iii) guidelines to allow data interpretation. By doing more studies on this subject, we can access this knowledge and support our perceptual evaluations with low-cost instrumental measurements.

One of the few acoustic studies concerning sibilants is conducted by Tjaden and Tumer[24] used SMA to characterize spectral moment features of 2 fricatives /s/ and /ʃ/ in amyotrophic lateral sclerosis (ALS). For speakers with ALS, the difference in M1 and L3 between the 2 fricatives was less than for typical speakers. McRae, Tjaden, and Schoonings[25] utilized SMA to identify spectral distinction between /s/ and /ʃ/ in 7 patients with Parkinson's disease. Like ALS, elderly speakers with Parkinson's disease have decreased spectral distinction for /s/ and /ʃ/.

It is also accepted that SMA is a practical measure of speech production skills in children with cleft palate. It is known that VPI affects the duration, amplitude, and spectral shape of fricative sounds.[26] Esghi et al.[27] used SMA for spectral analysis of word initial alveolar and velar plosives in Persian speaking children with CLP. They found that children with CLP had a quite decreased M1 of /t/ and /t/-/k/ difference. Jiang et al.[28] investigated spectral properties and perception of affricates in Putonghua-speaking individuals with and without cleft palate. Jiang et al.[7] analyzed spectral moment of affricates of Mandarin-speaking individuals with cleft palate. As stated in this study, pre-adolescents with repaired cleft palate showed a lower M1 of 4 affricates in Mandarin. Zajac et al.[29] examined the spectral characteristics of mid-dorsum palatal stops of English-speaking children with CLP. They reported that children with CLP using mid-dorsum palatal stops had lowest M1 for /t/. Moreover, the first moments of /k/ was also lowest for this group than the CLP and control group. Kalita et al.[30] have studied the acoustic characteristics of voiceless sibilant fricatives /s/ and /ʃ/ of normal and CLP children distorted by nasal air emission in Kannada language. In this study, it has been concluded that spectral moments of /s/ and /ʃ/ are different and a distinguishing feature in normal and CLP children. When comparing the CLP and control group, it has been found statistically significant that CLP children have a lower M1 and higher L3 for /s/; a lower M1 and higher M2 for / ʃ /.

There is only one study in the Turkish language investigating the acoustic properties of fricatives. Ertan[31] measured spectral properties, duration, overall amplitude, F2 transition, and M1 of fricatives in Turkish. However, there has been no study regarding the acoustic properties of cleft palate speech, spectral moment analysis on cleft lip and palate speech, and/or other related speech disorders in the Turkish language. Therefore, the aim of this study is to determine the acoustic and spectral properties of sibilants in Turkish-speaking children with typical development and hypernasality resulting from cleft palate and to investigate how hypernasality affects the acoustic properties of Turkish sibilants.

Methods

In this study, the effect of hypernasality on the acoustic properties of the Turkish sibilants (/ s, z, ʃ, ʒ /) has been investigated. One of the aims is to reveal how hypernasality and cleft palate affect the duration and voicing duration of sibilants. In terms of spectral moments, the aim is to investigate the concentration, peakedness, and tilt of the spectrum rather than its spread. Therefore, duration, voicing duration, center of gravity, skewness, and kurtosis have been analyzed as acoustic variables.

Participants

The participants of the study were 4 children with cleft palate (CP) (age range: 10-12; 2 females and 2 male) and 4 of their age and gender-matched peers having neither cleft lip and palate nor any speech, hearing, and language problems (NCP). Because sibilant sounds can be affected by many factors, inclusion criteria were strictly narrowed. The inclusion criteria for the CP group were as follows: (i) having hypernasality after primary surgery, (ii) not having oronasal fistula or malocclusion, (iii) not having any syndrome, (iv) having no language, hearing, and speech problems except hypernasal resonance, and (v) not wearing any palatal device. Participants in the CP group did not have either compensatory or obligatory speech sound errors; the only problem seen was the hypernasality. In other words, they all had correct speech sound productions including sibilants regarding the place, manner, and the voicing of articulation when plugging their nose. Given such strict inclusion criteria, it was quite difficult to reach many participants as malocclusion and/or fistula and speech sound errors were frequently seen in children with cleft lip and palate. All the inclusion criteria were applied to the NCP group as well, except having hypernasality and cleft palate. Both groups were monolingual Turkish-speaking children with typical development. To assess the inclusion criteria for participants, 2 speech and language pathologists having experience, particularly in CLP applied the following tests: Turkish Cleft Lip and Palate Assessment Form[32], Turkish Articulation and Phonology Test,[33] Nasometric Evaluation and NADA-Turkish Nasometric Evaluation Form.[34]

Speech Stimuli

Four target sounds (/s, z, ʃ, ʒ/) were placed word initially into 2-syllable words. Target sounds were preceded and followed by the vowel /a/ to control the coarticulatory changes. Each target sound occurred 3 times in different words, thus yielding 12 tokens. All of those words were placed into the same carrier phase to avoid prosodic influences (Arda …… dedi / Arda said…….) and presented to participants in 5 randomized lists. In total, 480 tokens (8 participants × 4 target sounds × 3 words × 5 lists) were analyzed.

Experimental Set-up

The study protocol was approved by the Ethics Committee of Anadolu University, Eskişehir, Türkiye (Approval no: 24874, Date: November 12, 2015). Before the recordings, all the participants were informed about

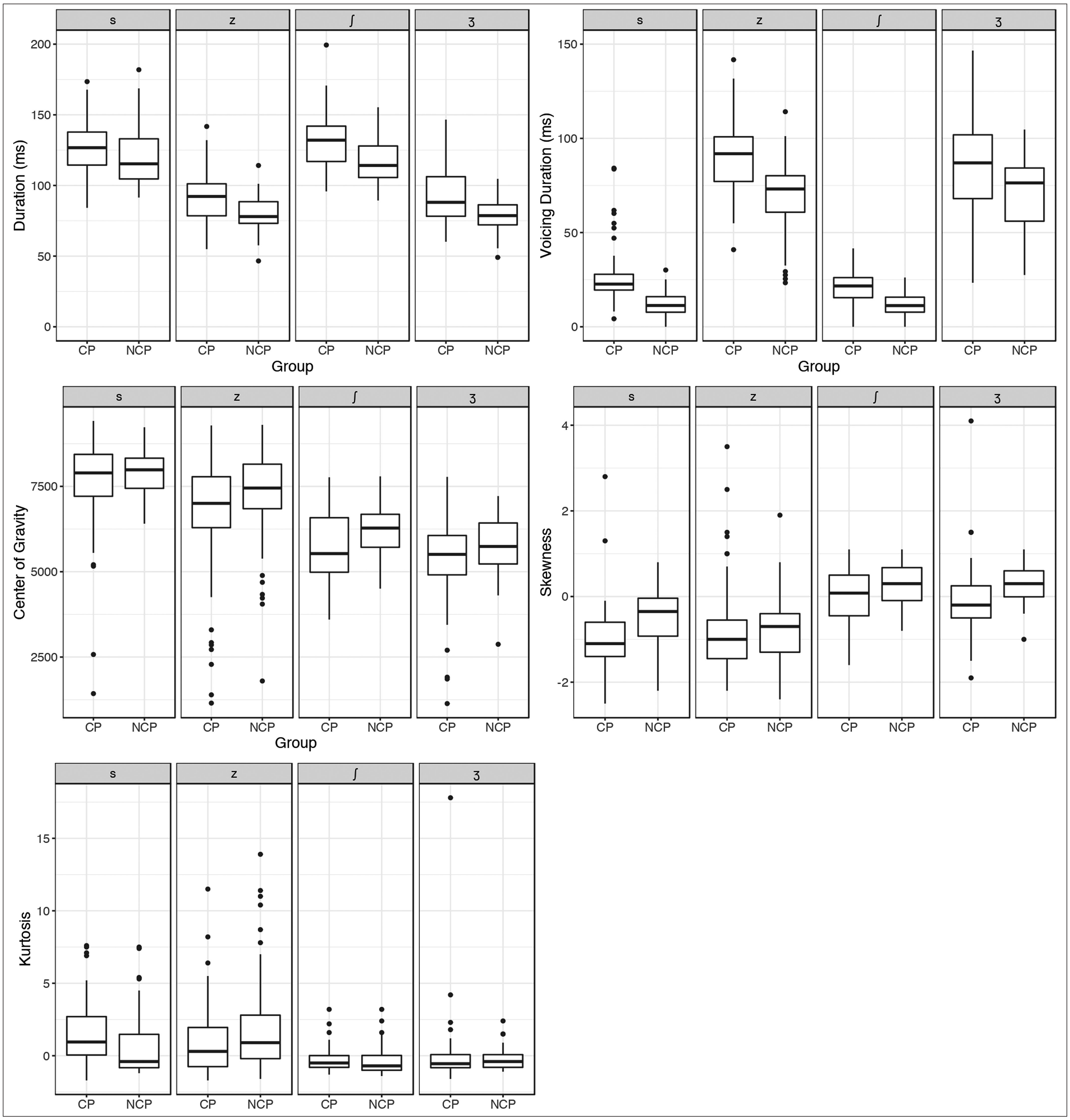

Figure 1. Comparison of groups in terms of duration, voicing duration, M1, L3 and L4 of the sibilant sounds CP, cleft palate group; NCP, non-cleft group.

the research and their consent was taken. The recording procedure was conducted at Anadolu University, Center for Speech, and Language Disorders' sound-padded phonetic laboratory. Acoustic recordings were obtained via a Sennheiser ME64 microphone at a 44.1kHz sampling rate using Computerized Speech Lab software.

The word lists were presented to the participants on a tablet computer, and they were asked to read the sentences in a normal tone and speed. The microphone was placed 15 cm away from the participant.

Data Analysis

First, all recordings were annotated manually in PRAAT.[35] While frication onset was marked at the earliest point at which an increase in the waveform's amplitude coincided with the presence of high-frequency energy in the spectrogram, offset was marked just before the vowel periodicity onset where energy intensity was at its lowest.[8,36,11] From these annotations, duration, voicing duration, center of gravity, skewness, and kurtosis values of Turkish sibilants were extracted via a script. This script obtained related data from the mid 20 ms of the labeled target.

Statistical Analysis

For all statistical analysis, linear mixed-effects models[37-39] using the lme4 package[40] in R[41] were used. In the model, hypernasality (CP, NCP) and targeted sibilant sounds (/s, z, ʃ, ʒ/) were included as fixed effects; participants were included as random effects. I used sum contrast to make the interpretations of coefficients more transparent. Significance levels were computed using lmerTest package.[42]

Results

In this study, the effect of hypernasality on sibilant sounds in terms of acoustic properties (duration, voicing duration, M1, L3, L4) was investigated. Figure 1 and Table 1 show the differences between groups and speech sounds.

Total duration and voicing duration of sibilant sounds tend to be longer for CP compared to the NCP according to Table 1. Furthermore, voiceless sibilants had a longer duration in comparison to the voiced cognates. While in the CP group, duration of /ʃ/ is the longest among sibilants (mean 133.93 ±22.06 ms), /s/ has the longest duration in the NCP group (mean 121.35 ± 22.95 ms). Values of M1 were notably higher in the NCP group. /s/ has the highest M1 in the NCP group (mean: 7969.74 ±657.54). Voicing and place of articulation also showed a difference in M1 values, such as M1 values were higher for voiceless compared to voiced partners and alveolar sibilants compared to postalveolar sibilants.

Figure 1 illustrates that L3 values for all sounds were higher in the NCP group. Alveolar sounds had negative values for both groups; however, postalveolar sibilants were positive for the NCP group. According to the place of articulation, while L3 values of /ʃ, ʒ/ in the NCP group are positive, /s, z/ are negative. L3 of voiceless sibilants of females in the CP group is located in negative zone.

The only dominant effect of L4 was seen in place of articulation; sounds /ʃ, ʒ/ had lower L4 values than /s, z/.

Table 2 shows the results of a linear mix-effects model. Contrary to expectations, hypernasality (comparison of groups) showed no effect on any of the dependent variables except voicing duration (β=14.95, P < .001). Although there were differences between groups on the plots, because of the limited number of participants, these differences are not reflected in the statistical analysis. As soon as the participants were added as random effects to the statistical model, the statistical significance was lost.

Table 1. Descriptive Statistics of Groups in Terms of Duration, Voicing Duration, M1, L3, and L4 of the Sibilant Sounds

		Duration (ms)				Voicing Duration (ms)				M1				L3				L4			
Gr.	Targ	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
CP	s	127.98	17.42	84.20	173.49	26.79	15.69	4.24	84.20	7546.51	1440.95	1429.2	9416.9	−1.01	0.81	−2.5	2.8	1.64	2.28	−1.7	7.6
	z	92.78	24.53	54.94	240.92	91.33	25.22	40.92	240.92	6675.41	1687.5	1150.8	9284.3	−0.86	1.01	−2.2	3.5	0.97	2.4	1−.7	11.5
	ʃ	133.93	22.06	95.83	210.98	20.43	8.74	−0.31	41.61	5813.65	1051.47	3599.3	7765.8	−0.02	0.64	−1.6	1.1	−0.30	0.81	−1.3	3.2
	ʒ	90.66	19.96	60.18	146.59	86.66	23.81	23.36	146.59	5280.01	1504.67	1136.7	7778	−0.05	0.98	−1.9	4.1	0.24	3.05	−1.6	17.8
NCP	s	121.35	22.95	91.47	201.35	12.01	5.70	0	30.12	7969.74	657.54	6407.8	9231.4	−0.47	0.64	−2.2	0.8	0.63	2.19	−1.2	7.5
	z	79.78	11.50	46.59	114.15	68.21	19.83	23.36	114.15	7288.30	1304.79	1798.5	9302.7	−0.82	0.84	−2.4	1.9	1.96	3.25	−1.6	13.9
	ʃ	118.46	17.54	89.39	155.33	12.13	5.58	0	26.15	6210.56	735.78	4505.3	7793.8	0.28	0.44	−0.8	1.10	−0.35	0.97	-1.4	3.2
	ʒ	78.46	11.60	49.09	104.65	69.97	20.17	27.48	104.65	5759.64	880.12	2874.0	7216.5	0.29	0.45	−1.0	1.10	−0.24	0.76	−1.1	2.4

Table 2. The Results of a Linear Mix-Effects Model Conducted to Estimate the Effect of Hypernasality and Targeted Sibilant Sounds (Differ by Place of Articulation and Voicing Features) on Dependent Variables (Duration, Voicing Duration, M1, L3, L4)

Dependent Variable		Intercept	$Group_{NCP\text{-}CP}$	$Sound_{/z/\text{-}/s/}$	$Sound_{/ʃ/\text{-}/s/}$	$Sound_{/ʒ/\text{-}/s/}$
Duration	Estimate	85.88	11.17	−38.56	1.84	−39.37
	Std. Error	3.98	7.58	1.77	1.90	2.10
	P	<.001***	0.191	<.001***	0.332	<.001***
Voicing duration	Estimate	77.88	14.95	60.41	−2.14	60.68
	Std. Error	2.08	3.46	1.69	1.80	2.02
	P	<.001***	<.005**	<.001***	.23	<.001***
M1	Estimate	5599.45	−350.36	−495.84	−1834.45	−2147.44
	Std. Error	234.14	452.13	89.91	94.46	106.54
	P	<.001***	.46	<.001***	<.001***	<.001***
L4	Estimate	−0.20	−0.05	0.16	−1.31	−1.19
	Std. Error	0.40	0.76	0.18	0.19	0.21
	P	.62	.95	.37	<.001***	<.001***
L3	Estimate	0.01	−0.40	−0.18	0.92	0.85
	Std. Error	0.14	0.26	0.07	0.07	0.08
	P	.95	.17	<.005**	<.001***	<.001***

There was an effect of voicing on both duration and, of course on voicing duration. While the duration of voiced sounds /z/ ($\beta = -38.56$, $P < .001$) and /ʒ/ ($\beta = -39.37$, $P < .001$) were lower, voicing duration was higher (for /z/ $\beta = 60.41$, $P < .001$ and for /ʒ/ $\beta = 60.68$, $P < .001$).

M1 values were affected by both place of articulation and voicing. Post-alveolar sounds /ʃ/ ($\beta = -1834.45$, $P < .001$), /ʒ/ ($\beta = -2147.44$, $P < .001$) and also voiced cognates /z/ ($\beta = -495.84$, $P < .001$) had lower values than /s/. L4 values were lower for both /ʃ/ ($\beta = -1.31$, $P < .001$) and /ʒ/ ($\beta = -1.18$, $P < .001$) compared to /s/, while there was no difference in /z/. L3 values of both postalveolar sounds (for /ʃ/ $\beta = 0.92$, $P < .001$ and for /ʒ/ $\beta = 0.85$, $P < .001$) were higher than /s/. However, it was lower for voiced alveolar /z/ ($\beta = -0.18$, $P < .005$).

Discussion

It has been deduced in this study that hypernasality affects the duration of target sounds. Accordingly, the duration of voiced-sibilant sounds of children with hypernasality is longer compared to children without hypernasality. This can be interpreted as a strategy thought to be developed by children with hypernasality; these children extend the duration of sounds to create intraoral pressure and generate voicing.

The duration of target sounds in both groups gets longer as the place of articulation moves back. This finding supports other studies.[16,26] This may be related to the reduction of narrowing in the anterior cavity. In other words, as the place of articulation moves back, the narrowing created by the tongue will also move back, and thus the path for the air to exit from the oral cavity will lengthen. Moreover, the duration of voiced sibilants is shorter than that of voiceless ones. This finding is similar to other acoustic studies in Turkish.[31,43]

The result of the research shows that gender has an effect on the duration of target sounds. Accordingly, whereas in the CP group, female participants' sounds were longer than males, it was found that the sibilant durations of males in the NCP group were longer than those of the females. Fox and Nissen[16] stated in their study that gender is not a distinctive feature for the duration of target sibilant sounds and there is no statistically significant difference for /s/ and /ʃ/ between genders. In addition, Maniwa, Jongman, and Wade[9] concluded that although speakers varied widely in some acoustic properties, such differences were not related to speakers' gender. However, in Ertan's[31] study, gender makes a difference for fricatives. Accordingly, except for the /ʒ/ sound, the duration of the sibilant voices of females is longer than that of males.

The M1 varies depending on the narrowing in the anterior cavity: the further the narrowing in the anterior cavity, the higher the M1. Results show that the M1 varies according to the hypernasality. M1 of participants in the NCP group is higher than the other group. This is thought to be related to the backing articulatory characteristic of individuals with cleft palate.

In this study, /s/ has the highest M1 in both groups and the M1 decreases as the place of articulation gets posterior. This finding is consistent with other studies.[8,13,16,17,44] In addition, similar findings were observed in Ertan's study for Turkish.[31] Accordingly, the M1 for /s/ is higher than the /ʃ/ sound, and the M1 of the voiceless sibilants is higher than their voiced pairs. According to another finding obtained in this study, gender has an effect on the M1: the M1 value of the female participants in both groups is higher than that of males. This finding is consistent with Fox and Nissen,[16] Haley et al.[17] and Ertan.[31]

As a result of the study, no difference was observed in the L3 values between the groups. In other words, hypernasality is not a factor making any change in L3. This suggests that the positive or negative slope of the energy distribution is not related to velopharyngeal closure. The most obvious difference seen in the L3 is in the place of articulation. Accordingly, as the place of articulation moves back, the L3 increases. In this analysis, the L3 of the /ʃ, ʒ/ sounds was found to be higher than the alveolar /s, z/ sounds. In the group of NCP, /ʃ, ʒ/ sounds were positively skewed, while /s, z/ sounds were negatively skewed. Energy distribution shows positive skewness at low frequencies. These findings match up with many studies.[8,13,17,44] However, according to Tomiak[45] and Avery and Liss,[46] the L3 of the /s/ is higher than the /ʃ/ sound.

Another finding in our study is that the L3 has a statistically borderline significance in male participants. In both groups with and without CLP, the L3 of male participants was relatively higher than that of females. This finding is similar to Jongman et al.[8] and Fox and Nissen's[16] studies. On the other hand, Nissen[44] stated that gender does not make a statistically significant difference in the L3.

The L4 values of the sibilants of the children with CLP were found to be lower than those of the children without CLP. In other words, children with hypernasality have a flatter spectrum compared to participants without hypernasality. Velopharyngeal dysfunction is thought to have an effect on the L4. According to the results of the study, one of the biggest differences seen in L4 is the place of articulation. As the articulation becomes more posterior, a decrease in the L4 value is observed: the L4 of /s, z/ sounds is higher than that of /ʃ, ʒ/. Phonetically, this can be interpreted as; on the one hand, the spectrum of /s, z/ sounds is much clearer, and the peaks are sharper; on the other hand, the spectrum of /ʃ, ʒ/ sounds with a lower kurtosis seems flatter. Studies by Jongman et al.,[8] Nissen,[44] Fox and Nissen,[16] and Nittrouer's[13] have the same findings.

Another effect seen on L4 is the gender variable. The L4 of male participants is lower than that of females. This finding is consistent with the study of Jongman et al.[8] In this study, it was found that the spectral views of females have clearer peaks and more distinct energy densities towards higher frequencies compared to males. However, Fox and Nissen[16] stated that gender is not a distinctive feature for distinguishing sounds in terms of kurtosis.

Conclusion

In conclusion, this study demonstrates that cleft lip and palate and associated hypernasality have an effect on some acoustic properties. As a result of the research, it was observed that hypernasality affects the duration of target sibilants. The duration of sibilant sounds in children with hypernasality is longer than in children without. In addition, M1 and L4 are other spectral properties affected by hypernasality. Children with hypernasality were found to have lower values in terms of M1. Similarly, the value of L4 was lower in children with cleft palate with hypernasality. However, hypernasality did not cause any change in L3.

The small number of participants can be a limitation for the study. It is recommended that larger samples can be included in further studies.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of Anadolu University University (Approval no: 24874, Date: November 12, 2015).

Informed Consent: Written informed consent was obtained from all participants who participated in this study.

Peer-review: Externally peer-reviewed.

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