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The Effect of Mixed Articulation Therapy on Perceptual and Acoustic Features of Compensatory Errors in Children with Cleft Palate

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Abstract

Background: Compensatory errors are a conventional part of an articulation disorder identified by speech pathologists in patients with Cleft palate (CP). This study aimed to evaluate the effect of new mixed articulation therapy on the perceptual and acoustic features of these errors.

Methods: The single-case experimental design, ABA design, was used in this study. Five CP young children ages 3.9 to 5.4 months, received online multimodal articulation therapy for 5 weeks, 6 sessions per week, utilizing both standard and maximum opposition approaches. Patients underwent baseline and follow-up sessions before and after treatment for 3 weeks—1 session per week. The percentage of compensatory errors was calculated as a perceptual measure, and 2 acoustic measures—including the slope of the locus equation (LE slope) and the overall F2 Transition Frequency Extent (TFE)—were analyzed.

Results: Compensatory errors were eliminated in all 5 participants with the mixed articulation therapy (Percentage of nonoverlapping data [PND] ≥80%, percentage of Improvement Rate Difference [IRD] ≥73.33%), and this therapy effect was maintained for up to 3 weeks of follow-up. The acoustic measures showed a difference in the F2 changes during CV transition in compensatory error before and after therapy.

Conclusion: This study supports the hypothesis that online mixed articulation therapy in children with CP can eliminate compensatory errors. The results of this study can also help extend the knowledge about F2 changes during CV transition in compensatory error before and after speech therapy to create objective and visual diagnostic documentation for patients with CP and prediction of some coarticulation models.

Keywords: Cleft Palate, Articulation Therapy, Compensatory Errors, Acoustic analysis, Perceptual Assessment

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Introduction

Compensatory errors are a conventional part of an articulation disorder identified by speech pathologists in patients with cleft lip and palate (CLP) (1). Articulation therapy is needed to eliminate these errors. Some researchers added phonological principles to the articulation-based approach to compensatory error corrections because these errors have a phonological origin with phonetic appearance (1-3).

The golden standard of speech assessment in patients with CLP is perceptual assessment (4). In addition to perceptual assessment, spectrography, which monitors the acoustic information of a speech signal, can be used in diagnosis, therapy, and assessment procedures (5, 6). Acoustic speech analysis can provide objective and effec-

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↑***What is "already known" in this topic:***
Compensatory errors are the most common disorders in children with cleft palate, and traditional articulation therapy can eliminate them.

→***What this article adds:***
Combining traditional and maximal opposition contrast approaches via telepractice can eliminate compensatory errors. The results of this study can also help extend the knowledge about F2 changes during CV transition in compensatory error before and after speech therapy.

tive diagnostic visual documentation for speech pathologists and patients (4, 7). Recent studies have dealt with the acoustic analysis of compensatory errors in patients with CLP (6, 8). The place of sound articulation changes in compensatory errors, and the measure of F2 transition can provide objective and quantitative information about the articulation place (9, 10). The overall F2 transition frequency extent (overall F2 TFE) can be obtained from the difference between the F2 onset value (F2i) and the F2 steady-state of the vowel (F2t), which determines the value and the trend of the F2 change in formant transition (11). It seems that the use of overall F2 TFE can provide information about the articulation strategy of compensatory errors, as the F2 change indicates the amount of articulatory transition, such as actual tongue movement.

At the CV boundary, the formants change due to anticipatory coarticulation with the following vowel. The degrees of articulatory constraint (DAC) values are assigned to the consonants and vowels based on the degree of involvement of the tongue dorsum in closure or constriction formation. Given the DAC model (12), consonants involving the movement of the tongue dorsum are more resistant to coarticulation than those with a more fronted articulation. Farnetani and Recasens (13) have discussed coarticulatory theories and models in speech production, among which the locus equation (LE) is explained as a measure of coarticulation. The LE is a regression line equation resulting from the changes in the F2i based on the F2t at the consonant-vowel (CV) boundary (F2i = k * F2t + c) (14, 15). The LE can indirectly cue articulation place by quantifying the degree of the coarticulation between the consonant and the vowel directly (13, 16). Therefore, it seems that using the LE slope during the CV transition can be valuable for identifying compensatory errors and determining therapeutic effects.

In Persian, there is little information about the speech of patients with CLP, especially the acoustic features of compensatory errors in constriction location, such as F2 transition. Some researchers concluded that there is little evidence to support the effectiveness of different interventions in children with CLP, and it is better to combine the traditional-based approach with the phonological-based approach. (17-19). Compensatory errors in children with cleft palate (CP) initially require a multisensory articulation-based approach—eg, auditory-visual-tactile-motor—to teach the correct position and manner of sound. Considering the phonological origin of these errors and the requirement to stabilize and generalize the learned sounds, a phonological-based approach can be used (5). Farquharson et al (19) concluded that it is better to consider treatment outside the framework of traditional therapy and use phonological-based approaches that focus more on phonological awareness and speech perception skills or can be easily provided through online treatment. The maximal opposition contrast method was used in this study because this newer phonological-based approach is suited for children with multiple errors such as CP. The selection of sound pairs with the most differences in this method can facilitate generalization, lead to significant changes in the individual's sound system, and help to understand the phonological system (20). According to the literature review, it is assumed that combining traditional therapy with the maximal opposition contrast approach can reduce the speech errors of children with SSD, suc as cleft palate. Some researchers used the combination of the minimum pair and distinctive features method (phonological-based approaches) with the traditional approach (articulation-based approach) (1, 3), and a study that combines the maximal pair method and the conventional method is nonexistent. Pamplona et al (21) used online therapy to reduce compensatory errors. Some researchers have investigated the advantages and disadvantages of online therapy and its impact from the parents' perspective of children with CP, and parents have reported online treatment to be "somewhat effective" (22, 23). In Iran, patients may need online medical services because of numerous problems with face-to-face therapy. Considering the phonological origin of the compensatory errors and the need for research in the field of the effect of the combination of articulation and phonological-based approaches on the perceptual and acoustic features of these errors, as well as considering the problems that exist in access to specialized cleft centers in these patients, this study aimed to analyze perceptual and acoustic features of compensatory errors before and after new online mixed articulation therapy.

Methods

Participants

Following an examination of the 1100 clinical records of patients in the CLP team at the hospitals Hazrat-e Fatemeh and Hazrat-e Aliasghar, Iran University of Medical Sciences (IUMS), the records were examined using the following inclusion criteria: A speech pathologist's informal language assessment (language sample analysis 24) and health records were required. The children had to be Persian-speaking, monolingual, and between the ages of 3 and 6 years. They also had to fall into at least 1 of the 4 categories of compensatory errors, with at least 1 impaired consonant based on the expert assessment of the speed of the errors. Finally, there could not be any specific syndromes or cognitive and language impairments; 17 families were phone interviewed in accordance with the exclusion criteria—having fistula, lack of cooperation, no adequate speech samples. In the end, 5 families met the requirements and expressed a desire for their kids to take

Table 1. Characteristics of subjects in terms of Cleft type, Percentage of non-oral CTCs, Rating of hypernasality, Gender, and Age

Patient number	Cleft type	Percentage of non-oral CTCs	Rating of hypernasality	gender	Age (years)
P1*	CP*	17.85	Severe	F*	5.4
P2	SCP*	39.28	No	F	4.9
P3	CP	10.71	Moderate	M*	3.9
P4	SCP	50	Borderline	F	4.4
P5	CP	10.71	Severe	F	4.5

Participant (P), Cleft Palate (CP), Female (F), Soft Palate Cleft (SCP), Male (M) part in this study. Table 1 displays the descriptive data provided by the participants. The IUMS Regional Ethical Committee authorized the collection of patient data (ethical code: IR.IUMS.REC.1400.422), and the parents provided signed informed consent.

Study Design

This study had an ABA design and consisted of 3 phases as follows:

The First Phase—Baseline

We used the headset microphone, AKG model, held at a 10-cm distance from the child's mouth in a quiet room, with a noise level of <40 dB SPL, at Hazrat-e Fatemeh Hospital to evaluate and record the acoustic and perceptual measures (See detailed information in the speech sample and measuring sections). At this phase, the children did not receive any therapy, and face-to-face assessment was conducted and recorded weekly over 3 weeks (25). Thus, 3 data points were obtained.

The Second Phase—Intervention

At this phase, 45-minute online intervention sessions for 30 sessions were conducted 6 sessions per week for 5 weeks. The treatment dose was determined based on the effectiveness of the treatment on variables, the possibility of parents' participation in the treatment, and previous studies (1, 3). A combination of traditional therapy, articulation-based approach, with maximal opposition contrast therapy, phonological approach, was used to correct errors, especially compensatory errors (5, 20, 26). First, the proper sounds were taught using the standard method; thereafter, the maximum pair strategy was employed to create a difference between the target sounds and aid in generalization. The therapist determined the precise therapeutic goals for each child by considering factors such as the target sounds' location, voice, stability, and articulation stimulability. After determining the particular therapy goals and getting the child's cooperation, the necessary feedback was given to the child to extract the sound and follow the treatment process during the therapy sessions. One of the parents was present to help the child implement the methods and to receive the necessary information to perform the homework in all sessions. If necessary, video or audio files were used to teach parents. The WhatsApp application was used to make video calls because of availability and ease of use when there was no filtering. One experienced speech pathologist (the first author) provided therapy to all children. Five data points were obtained through face-to-face evaluations at the end of each week.

The Third Phase—Follow-up

At this phase, the children did not receive any therapy, and face-to-face assessment was conducted and recorded weekly for 3 weeks (25). Therefore, 3 data points were obtained.

Speech Sample

Perceptual Assessment

Repetition of Persian words set according to the universal parameters instruction by all children was recorded. This word set is a reliable tool for evaluating CP speech errors and assesses 14 high-pressure consonants in the first and last positions (Appendix) (27). Pharyngeal and glottal articulation, active nasal fricative, and double articulation were considered compensatory errors (28, 29). First, 3 experienced speech pathologists, with an average of 7 years of experience evaluating and treating patients with CP, performed a perceptual assessment. Because of the high reliability among the assessors, 1 assessor analyzed other speech samples. The percentage of compensatory errors was assessed blindly at the baseline, intervention, and follow-up data points.

Acoustic Assessment

All the children were asked to utter a set of Cɑ syllables, C stands for 14 high-pressure consonants with the vowel /ɑ/) (Appendix). All audio-recorded samples in the third and ninth assessment sessions, before and after the therapy, were played back through over-ear headphones and were transcribed phonetically by 4 speech pathologists with 4 to 10 years of experience working on CP. In general, compensatory errors were selected for acoustic analysis that occurred at the Cɑ level and were fully agreed upon by 4 speech pathologists before (ie, agreement on compensatory errors) and after (ie, agreement on the correct consonant) the therapy. Compulsory errors were investigated in speech with no hypernasality in participant number 2 (P2) to eliminate the effect of hypernasality on formants. Two of the investigators, the first and the third authors who were highly experienced in acoustic analysis, determined the acoustic variables. They reached a consensus on the F2 onset and F2 steady-state points. They were blinded as to which samples were from before or after the therapy.

Measures

Perceptual Measure

According to the following formula, the percentage of compensatory errors was obtained by counting the number of them in the first and last positions of the target sound (see the sample speech section) divided by their total (total number =28) (1).

mpensatory errors = (The number of compensatory errors)/28× 100

Acoustic Measures

The acoustic signal was captured with an electret condenser headset microphone. Praat software Version 4.6.01 was used for all the stages of display and measurement. Burg-LPC settings in Praat were used for formant measuring (30). 10th linear predictive coding (5 formants), with a maximum formant of 5500 Hz, was used to capture formants. The F2 frequency was measured by visually examining the LPC formants and spectrogram at the following points: F2 onset and F2 steady state.

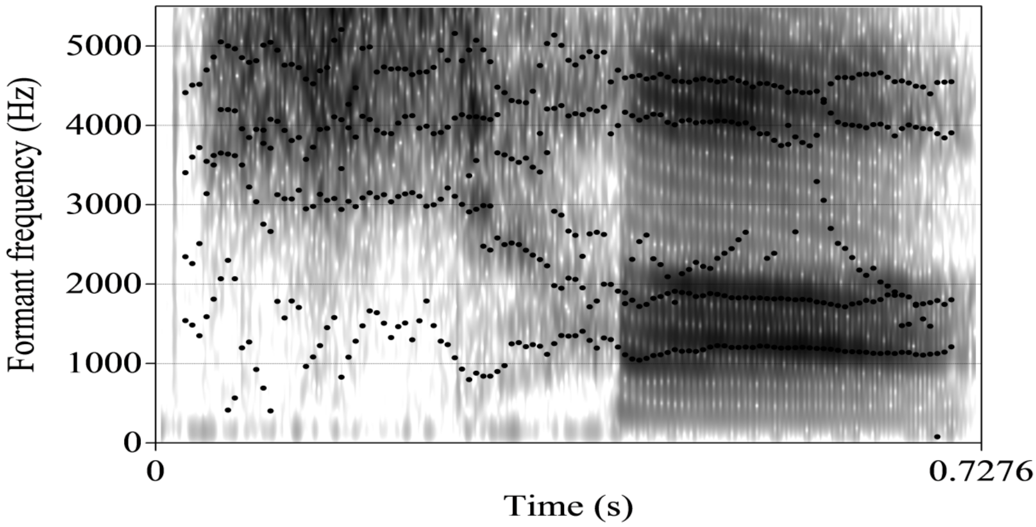

Figure 1. Spectrograms of /ʧɑ/ showing sites for F2 onset, and F2 steady state measurements.

F2 onset: The F2 onset was the earliest visible F2 resonance determined after burst release in the spectrographic display (31). We measured F2 onset on the first pitch period at the end of the release of the consonant.

F2 steady state (F2 vowel): The point at which the F2 of the vowel /ɑ/ was stabilized was taken as F2 steady state (31). If no stability was observed during the vowel, a midpoint of the vowel was taken as an F2 steady state (32).

Figure 1 represents a spectrogram of the syllable /ʧɑ/, which was produced by P2 in the ninth assessment session. This figure shows sites for F2 onset and F2 steady state.

To derive the equation of the regression line (F2i = k * F2t + c) (14, 15), the values of the ordered pairs < F2i, F2t > were obtained for 5 repetitions of the Cɑ boundary (consonant: /k/, /ʧ/, /x/). The locus equation (k) slope was calculated by deriving locus equation scatterplots after entering these pairs into Microsoft Excel. The slope of the locus equation was obtained from the changes in the F2 onset value (F2i) based on the value of the F2 steady-state of the vowel (F2t).

The overall F2 TFE (11) was obtained from the difference between the F2 onset and F2 steady-state mean for 5 repetitions of the Cɑ boundary.

The articulatory correlate of LE slope and overall F2 TFE refers to the coarticulation of C to V.

Statistical Analysis

The percentage of nonoverlapping data (PND) and percentage of improvement rate difference (IRD) were used as 2 effect size indices to analyze the perceptual data (33). All the analyses were performed using IBM SPSS Version 17 software and Microsoft Excel 2010.

Reliability

The intrarater and interrater reliability were rated very good for compensatory errors (Cronbach's alpha > 0.9).

Results

Perceptual Analysis

Table 2 presents the percentage of compensatory errors at 11 data points. The measurements were stable at the baseline phase. A significant decrease is observed in the percentage of errors in all 5 children with the onset of the intervention phase. The percentage of compensatory errors at the end of the follow-up period reached zero in all the children.

Effect Size Calculation

Table 3 presents the PND and IRD. As shown in Table 3, the PND and IRD scores indicate that the mixed articulation therapy was highly influential in decreasing compensatory errors for all the patients (PND ≥80%, IRD ≥73.33%).

Acoustic Analysis

Glottal stop in the /kɑ/, /ʧɑ/, and /xɑ/ syllables before and after therapy in P2

The overall F2 TFE change in the /kɑ/, /ʧɑ/, and /xɑ/ syllables before and after therapy is shown in Figure 2.

Table 2. Percentage of non-oral CTCs in baseline position, intervention, and follow-up for five patients

Patient number	Baseline data points			Intervention data points					Follow-up data points		
	First	Second	Third	4th	5th	6th	7th	8th	9th	10th	11th
P1	17.85	17.85	17.85	17.85	10.71	7.14	3.57	0	0	0	0
P2	35.71	35.71	35.71	28.57	17.85	10.71	3.57	0	0	0	0
P3	10.71	10.71	10.71	7.14	10.71	3.57	0	0	0	3.57	0
P4	50	50	50	42.85	39.28	35.71	35.71	0	0	0	0
P5	10.71	10.71	10.71	10.71	7.14	7.14	3.57	0	0	0	0

Table 3. The scores of PND and IRD in non-oral CTCs in five patients were measured as %

Patient number	PND	IRD
P1	80%	73.33%
P2	100%	100%
P3	80%	73.33%
P4	100%	100%
P5	80%	73.33%

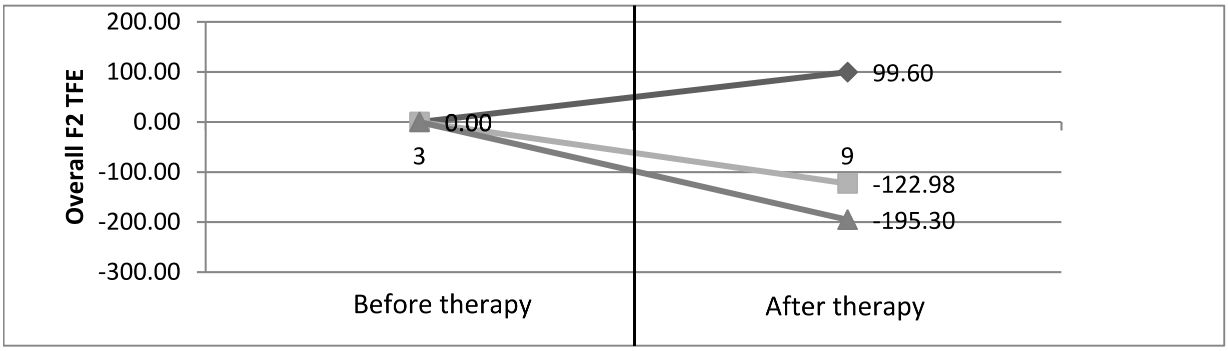

Figure 2. Overall F2 Transition Frequency Extent (Overall F۲ TFE) in the /kɑ/, /ʧɑ/, and /xɑ/ syllables before and after therapy in P2
Legend:

kɑ ʧɑ xɑ

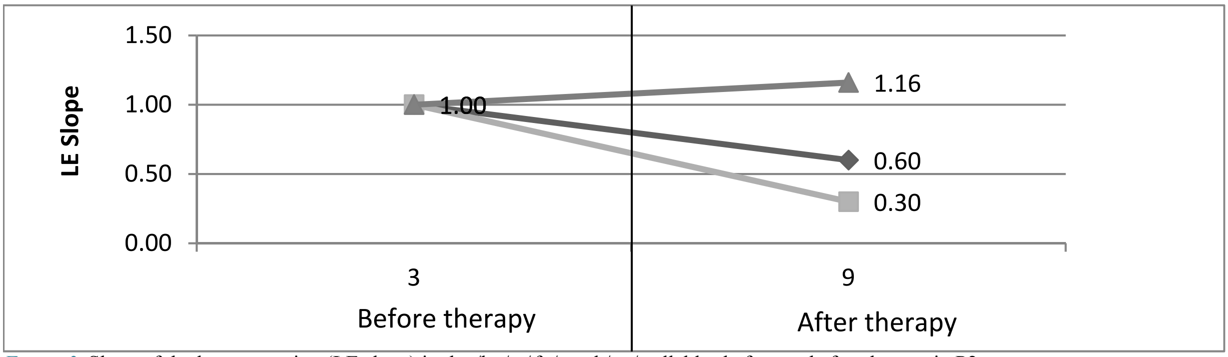

Figure 3. Slope of the locus equation (LE slope) in the /kɑ/, /ʧɑ/, and /xɑ/ syllables before and after therapy in P2
Legend:

kɑ ʧɑ xɑ

The overall F2 TFE in these syllables changed after treatment.

The LE slope change in the /kɑ/, /ʧɑ/, and /xɑ/ syllables before and after therapy is shown in Figure 3. As shown in Figure 2, the LE slope in these syllables changed after treatment.

Discussion

Online Mixed Articulation Therapy

The results showed the effect of intensive online mixed therapy—traditional and maximal opposition contrast approaches—on eliminating compensatory errors in all studied children. However, more studies should compare the results of this type of therapy with the traditional method alone. There is no difference in the percentage of compensatory errors when comparing the data points at the baseline and follow-up phases in Table 2. It indicates the stable measurements before speech therapy at the baseline phase and the consistent ability of correct sound production after speech therapy. It is also noticed that the percentage of compensatory errors decreases immediately following the intervention, reaching zero at its conclusion. This finding is in line with the results of Derakhshandeh et al (1), Aligiri et al (3), and Pamplona et al (21). They showed a decrease in the percentage of compensatory errors in patients with CP after speech therapy. However, they used different methods, and future studies can compare them with each other. The reported indexes of the effect size (IRD and PND) in Table 3 also confirm these results and show the high effect of intensive mixed articulation therapy on compensatory error reduction (PND ≥80%, IRD ≥73.33%).

In this study, because of the need for weekly evaluations and intensive treatment during the COVID-19 pandemic, online intervention was selected. Failure to conduct follow-up speech therapy sessions can lead to a lag in the necessary interventions in patients with CP. When faced with challenges like the COVID-19 epidemic, lack of access to team services and qualified specialists, distance, financial challenges, or time constraints, online therapy can help prevent treatment sessions from being postponed. This study's findings, which show that online therapy can lower compensatory errors, are consistent with those of Pamplona et al (21). Future research comparing various therapy methods in person and online is advised, given the variation in the therapy approach used.

Acoustic Analysis

As shown in Figure 2, the overall F2 TFE was 0.00 Hz before therapy; thus, there was no F2 change in the glottal stop coarticulated with an open vowel (/ʔɑ/). Given that the articulation place of the glottal stop is in the glottis itself, it was expected that it would not affect the F2 onset of the vowel and that F2 would remain constant throughout the articulation of the /ʔɑ/ syllable. As shown in Figure 3, the LE slope was 1 before therapy; therefore, for every change in the F2 vowel, the same change occurred at the F2 onset. These 2 values were the same in the glottal stop, and F2 remained constant during the /ʔɑ/ syllable. If the LE slope for a given consonant place is close to 1 (F2 onset = F2 steady-state), the vowel-on-consonant coarticulation is assumed to be maximal (34).

As shown in Figure 2, articulation of the target consonants (/k/, /ʧ/, /x/) after therapy changed the F2 onset. F2 changes indicate that the amount of articulatory transition—such as actual tongue movement and vocal tract area function—change. Changing the overall F2 TFE in the /kɑ/, /ʧɑ/, and /xɑ/ syllables relative to the /ʔɑ/ syllable indicates a difference in articulation strategy, tongue movements, and degree of coarticulation before and after speech therapy (11). Figure 3 illustrates how the LE slope changed from 1 to indicate that there was less CV coarticulation following the proper articulation of /k/, /ʧ/, and /x/. Because the consonant /ʔ/ is articulated in the glottis, its coarticulation with the vowel /ɑ/ is higher than the consonants articulated in the mouth. Hence, a difference in the amount of slope was predictable.

In accordance with the DAC model of coarticulation, maximal accommodation was achieved prior to treatment for consonants with lower DAC values (/ʔ/). Thus, a higher level of coarticulation was noted (LE slop: 1, Overall F2 TFE: 0 Hz). The degree of coarticulation during the Cɑ syllables is reduced when different locations and degrees of tongue movements are required following speech therapy and shifting the articulation point of consonants from the glottis to the mouth and higher DAC value (12).

Our results align with the findings of some other researchers, who found that the LE slope may function as an invariant cue to place and describe the degree of vowel-on-consonant coarticulation (15, 32). Generally speaking, the coarticulation of C to V is indicated by the articulatory correlation of LE slope and total F2 TFE, and the findings could validate the predictions of several coarticulation models.

Strengths and Limitations

This study showed the positive effect of the new mixed therapy on the perceptual and acoustic features of compensatory errors. However, it had limitations, such as the small number of participants and the lack of instrumental evaluation usage. We could not recruit more participants because of the COVID-19 pandemic and the strict inclusion and exclusion criteria for CP studies.

Conclusion

Online mixed therapy—traditional therapy with maximal opposition contrast therapy—can lead to a statistically significant reduction of compensatory errors in children with CP. This study provides evidence that acoustic analysis of compensatory errors without hypernasality can provide objective and practical diagnostic visual documentation for speech pathologists and even patients. The acoustic variables related to the place of articulation, such as the LE slope and the overall F2 TFE, were used to evaluate compensatory errors.

Authors' Contributions

Mahdiye Tavakoli: conceptualization, formal analysis, investigation, validation, visualization, methodology, data curation, writing the original draft. Nahid Jalilevand: conceptualization, funding acquisition, methodology, supervision, writing, reviewing & editing. Mahmood Bijankhan: formal analysis, methodology, software, writing, reviewing & editing. Farhad Torabinezhad: formal analysis; methodology, software. Reyhane Mohamadi: formal analysis, methodology, writing, reviewing & editing. Noor Ahmad Latifi: resources, writing, reviewing & editing.

Ethical Considerations

This study was approved by the Ethics Committee in Research of IUMS (ethics code: IR.IUMS.REC.1400.422).

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Conflict of Interests

The authors declare that they have no competing interests.

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Appendix. List of the words of Universal Parameters in Persian

Target sound	Words	Persian words
/p/	/pɑ/, /tup/	پا، توپ
/b/	/bil/, /lab/	بیل، لب
/f/	/fil/, /lif/	فیل، لیف
/t/	/tɑb/, /sut/	تاب، سوت
/d/	/dar/, /dud/	در، دود
/s/	/sib/, /sos/	سیب، سس
/z/	/zir/, /boz/	زیر، بز
/ʃ/	/ʃir/, /riʃ/	شیر، ریش
/ʧ/	/ʧɑy/, /piʧ/	چای، پیچ
/ʤ/	/ʤuʤe/, /haviʤ/	جوجه، هویج
/k/	/kuh/, /keik/	کوه، کیک
/g/	/gol/, /gorg/	گل، گرگ
/ɢ/	/ɢuri/, /kalɑɢ/	قوری، کلاغ
/x/	/xɑk/, /jax/	خاک، یخ

The bolded letters are initial and final target consonants in word.