

Comparative Evaluation of Change in Phonetics Before and After Treatment of Skeletal Class III Malocclusion in Growing and Adult Patients: A Prospective Longitudinal Study

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Abstract

Background:

Skeletal Class III malocclusion can alter the relationship between the tongue, lips, teeth, and supporting oral structures, potentially affecting speech production. Although the skeletal effects of orthopedic and orthognathic treatment are well documented, evidence regarding treatment-related speech changes remains limited.

Objective:

To evaluate changes in speech sound production before and after treatment of skeletal Class III malocclusion and compare outcomes among growing patients treated with facemask therapy or bone-anchored maxillary protraction (BAMP), and adults treated with conventional orthognathic surgery or the surgery-first orthognathic approach (SFOA).

Materials and Methods:

A prospective longitudinal study was conducted in patients with skeletal Class III malocclusion. Participants were allocated into four treatment groups: facemask with bonded rapid maxillary expansion (RME), BAMP with bonded RME, conventional orthodontic–orthognathic treatment, and SFOA. Speech was assessed before treatment (T1) and after treatment completion (T2) using a standardized word list containing consonants commonly affected in Class III malocclusion. Recordings were evaluated for articulation errors.

Results:

All groups demonstrated improvement in speech sound production following treatment. The greatest reductions in articulation errors were observed for /s/ and /z/. Growing patients treated with BAMP showed greater improvement than those treated with facemask therapy. In adults, both surgical approaches reduced speech errors, with SFOA demonstrating greater improvement in selected speech parameters.

Conclusion:

Treatment of skeletal Class III malocclusion was associated with measurable improvement in speech sound production. Greater improvements were observed following BAMP in growing patients and SFOA in adults.

Keywords: Skeletal Class III malocclusion; Speech sound production; Phonetics; Bone-anchored maxillary protraction; Facemask therapy; Orthognathic surgery; Surgery-first approach.

Introduction

Speech is a complex motor function requiring coordinated movements of the tongue, lips, teeth, alveolus and surrounding oral structures. Since many speech sounds depend on precise contact or approximation between these structures, changes in dentoalveolar relationships can influence speech production. Orthodontic studies have reported speech sound errors in association with malocclusion, particularly involving consonants such as /s/ and /t/, with greater malocclusal severity being associated with an increased likelihood of speech errors.[1] The relationship between dentofacial morphology and speech extends beyond individual occlusal traits, as changes in incisor relationships can modify the space and contact patterns involved in articulation. Experimental and linguistic evidence has further demonstrated that changes in bite configuration can influence the production of specific speech sounds, highlighting the close functional relationship between oral morphology and speech.[2]

Skeletal Class III malocclusion provides a clinically relevant model for investigating this relationship because the discrepancy may arise from maxillary deficiency, mandibular prognathism, or a combination of both, often resulting

in reduced or negative overjet. These changes may modify the anterior oral environment required for accurate production of several consonants. In a large cohort of patients with Class III dentofacial disharmony, Lathrop-Marshall et al. reported a substantially greater prevalence of speech distortions than in reference subjects and demonstrated measurable acoustic differences in stop, fricative and affricate consonants.[3] Speech alterations have also been reported specifically in adults with skeletal Class III malocclusion. Frequent misarticulation has been described for sounds including /zh/, /ch/, /sh/ and /z/, with distortion and substitution being among the commonly observed error patterns and acoustic differences demonstrated between affected and normal productions.[4]

Correction of the underlying skeletal discrepancy may alter the articulatory environment; however, correction of the occlusion does not necessarily result in immediate normalization of an established speech pattern. This is particularly relevant in growing patients, as compensatory articulatory patterns may have developed before orthopedic treatment. In a recent study of children with skeletal Class III malocclusion and speech sound disorders, no significant improvement in speech abnormalities was observed six months after facemask therapy with rapid maxillary expansion, whereas improvement occurred following subsequent speech therapy.[5]

For growing patients with maxillary deficiency, facemask therapy with rapid maxillary expansion is an established orthopedic treatment approach. Although rapid maxillary expansion has commonly been incorporated into maxillary protraction protocols, its additional skeletal effect when combined with facemask therapy has not consistently been demonstrated.[6] Skeletal anchorage has subsequently been introduced to increase the orthopedic component of maxillary protraction and reduce reliance on dental anchorage. Bone-anchored maxillary protraction using maxillary and mandibular miniplates has demonstrated favorable sagittal skeletal effects in growing patients with Class III malocclusion, with randomized clinical evidence also supporting improvements in parameters such as ANB and overjet. Despite the extensive literature concerning the skeletal and dental effects of these treatment approaches, their influence on speech remains comparatively underexplored. In particular, there is limited evidence regarding whether speech changes differ between conventional tooth-anchored maxillary protraction and skeletal-anchored maxillary protraction, despite the differences in the manner in which these approaches modify the dentofacial relationship [7,8].

In skeletally mature patients with severe Class III discrepancies, correction may require orthognathic surgery involving repositioning of the maxilla, mandible, or both. Such skeletal repositioning produces a substantial change in the anatomical environment involved in speech production, and a systematic review and meta-analysis has demonstrated that orthognathic surgery can influence speech and voice, although the reported effects vary among different speech parameters.[9] Prospective evidence in skeletal Class III patients has further shown that articulation may continue to adapt during the postoperative period. Lal et al. reported that articulation errors did not change significantly during the first three to six months after orthognathic surgery but decreased substantially by approximately nine months, while overall speech intelligibility remained unchanged.[10]

The sequence of orthodontic and surgical treatment may also influence functional adaptation. Conventional orthognathic treatment involves presurgical orthodontic decompensation followed by surgical correction, whereas the surgery-first orthognathic approach (SFOA) performs skeletal correction before completion of conventional presurgical orthodontic preparation. In addition, orthodontic appliances themselves can temporarily influence speech production during the adaptation period, making the timing and conditions of postoperative or post-treatment speech assessment important considerations.[11]

Therefore, the present study aims to evaluate speech sound production before and after correction of skeletal Class III malocclusion in growing and adult patients and to compare the changes associated with different treatment approaches. Growing patients treated with facemask and bonded rapid maxillary expansion will be compared with those treated using customized maxillary miniplates and prefabricated mandibular L-shaped plates according to a BAMP protocol with bonded rapid maxillary expansion. In skeletally mature patients, speech changes following conventional orthodontic-orthognathic treatment and the surgery-first orthognathic approach will be evaluated. The study will further assess whether correction of the skeletal and occlusal relationship is accompanied by measurable changes in speech sound production and whether these changes differ according to skeletal maturity and treatment approach.

Materials and Methods

Ethical Considerations and Patient Consent

The study was conducted in accordance with the principles of the Declaration of Helsinki and after obtaining approval from the Institutional Ethics Committee of Saveetha Dental College and Hospitals. Written informed consent was obtained from all adult participants before enrolment. For participants below 18 years of age, written informed consent was obtained from a parent or legal guardian, along with assent from the participant where appropriate. Participants were informed about the study procedures, speech recordings, confidentiality, and their right to withdraw from the study at any time without affecting their treatment. All collected data and audio recordings were coded and maintained confidentially.

Study design

A prospective longitudinal clinical study was conducted to evaluate changes in speech sound production following treatment of skeletal Class III malocclusion. Participants were categorized according to skeletal maturity and the treatment protocol received.

The study comprised four treatment groups, with 20 participants in each group:

- **Group I – Growing Class III, facemask:** growing patients treated with facemask therapy combined with bonded rapid maxillary expansion (RME).
- **Group II – Growing Class III, BAMP:** growing patients treated with customized maxillary miniplates and prefabricated mandibular L-shaped plates according to a bone-anchored maxillary protraction (BAMP) protocol, combined with bonded RME.
- **Group III – Adult Class III, conventional surgery:** skeletally mature patients treated using the conventional orthodontic–orthognathic treatment sequence.
- **Group IV – Adult Class III, SFOA:** skeletally mature patients treated using the surgery-first orthognathic approach (SFOA), followed by postoperative orthodontic treatment.

The treatment modality was determined as part of the patient's established orthodontic or orthognathic treatment plan and was not influenced by the speech assessment.

The study groups and their baseline demographic and selected skeletal characteristics are presented in Table 1. The mean ages were 8.1 ± 1.2 years and 8.3 ± 1.3 years for the facemask and BAMP groups, respectively, and 23.8 ± 4.2 years and 24.1 ± 4.5 years for the conventional surgery and SFOA groups, respectively. Baseline ANB and overjet values were also recorded for characterization of the study population.

FIGURE 1:



Figure 1. Baseline speech-error incidence

Percentage of participants demonstrating each speech error before treatment across the four Class III treatment groups.

This figure corresponds to the baseline distribution reported in Table 2 and shows that /s/ and /z/ errors were the most prevalent speech abnormalities across all four groups.

Study participants

Patients diagnosed with skeletal Class III malocclusion who underwent one of the four predefined treatment protocols were considered for inclusion.

The growing groups consisted of patients undergoing orthopedic correction of the skeletal Class III discrepancy, whereas the adult groups consisted of skeletally mature patients requiring surgical correction of the Class III skeletal relationship.

Inclusion criteria

Participants were included if they fulfilled the following criteria:

1. Diagnosed skeletal Class III malocclusion.
2. Growing patients indicated for orthopedic Class III correction or skeletally mature patients indicated for orthognathic correction.
3. Treatment with one of the four predefined protocols.
4. Ability to understand and reproduce the speech stimuli used during assessment.
5. Adequate hearing for speech assessment.
6. Availability for both pretreatment and post-treatment speech assessment.

Exclusion criteria

Participants were excluded if they had:

1. Cleft lip and/or palate or other congenital craniofacial anomalies.
2. Craniofacial syndromes.
3. Neurological disorders known to affect speech production.
4. Known hearing impairment.
5. Previously diagnosed speech or language disorders unrelated to the skeletal malocclusion.
6. Previous orthognathic surgery or major maxillofacial trauma.
7. Inability to understand or reproduce the required speech stimuli.
8. Incomplete speech recordings at either assessment time point.
9. Any condition preventing completion of the planned treatment or speech assessment.

A history of previous speech therapy was documented and considered during interpretation of the speech findings.

Speech assessment

Speech was assessed using a structured speech-sound assessment developed for the present study. The assessment was performed by the principal investigator in a quiet clinical setting.

The selection of target sounds was based on speech characteristics previously reported in individuals with skeletal Class III malocclusion. Seven consonant targets were evaluated: /s/, /z/, /j/, /r/, /t/, /k/, and /tj/.

The speech assessment was designed to identify both the presence and type of speech sound error and, for selected phonemes, measurable acoustic characteristics.

Speech stimuli

A standardized word list containing the selected target consonants was used for all participants. The target sounds were presented in words selected to permit clear identification of the consonant during both perceptual and acoustic assessment.

The same speech stimuli and assessment sequence were used at the two assessment time points to maintain consistency between pretreatment and post-treatment measurements.

Speech assessment procedure

The assessment was conducted in a quiet room within the orthodontic clinic. Participants were seated comfortably and instructed to pronounce the selected words at a natural speaking rate and conversational loudness. Speech samples were recorded digitally for subsequent evaluation.

Each target speech sound was evaluated for the presence or absence of an articulation error. The following speech characteristics were specifically recorded:

- interdental /s/;
- interdental /z/;
- /j/ imprecision;
- rhotacism /r/;
- /t/ distortion;
- /k/ distortion; and
- /tj/ distortion.

An “any speech error” category was also recorded when a participant demonstrated at least one of the assessed speech abnormalities.

The same assessment procedure was followed at both pretreatment and post-treatment examinations.

Speech-error classification

Speech errors were classified according to the perceptual characteristics observed during production of the target consonants.

Interdental /s/ and /z/ were recorded when the tongue was positioned between the upper and lower anterior teeth during production of the respective fricative.

/j/ imprecision was recorded when the target sound was produced with an altered or indistinct articulatory quality.

Rhotacism /r/ was recorded when the production of the /r/ sound deviated from the expected articulatory pattern.

/t/, /k/ and /tj/ distortions were recorded when the target consonants were produced with an identifiable deviation from their expected articulation.

The presence or absence of each error was recorded for every participant.

Standardized speech recording

All speech samples were digitally recorded using the same recording protocol.

The recording environment, participant position, instructions and speech stimuli were standardized across participants and assessment sessions as far as practicable.

Each recording was assigned a study identification code. Participant names or other directly identifying information were not incorporated into the speech-recording files.

The recordings were retained for assessment of the predefined perceptual and acoustic speech outcomes.

Assessment time points

Speech was evaluated at two principal time points.

T1 — Pretreatment

The baseline speech assessment was performed before commencement of the respective treatment protocol.

For the adult surgical groups, this represented the preoperative assessment.

T2 — Post-treatment

The second assessment was performed following completion of the respective treatment protocol and after the predefined post-treatment/adaptation interval.

For the adult surgical groups, this represented the postoperative assessment.

The same speech stimuli, recording procedure and assessment criteria were used at T1 and T2.

Table 1. Demographic and baseline skeletal characteristics of the study groups

Parameter	Facemask (n=20)	BAMP (n=20)	Conventional surgery (n=20)	SFOA (n=20)
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Age, mean $\pm$ SD (years)	8.1 $\pm$ 1.2	8.3 $\pm$ 1.3	23.8 $\pm$ 4.2	24.1 $\pm$ 4.5
Male, n (%)	11 (55)	10 (50)	9 (45)	10 (50)
Female, n (%)	9 (45)	10 (50)	11 (55)	10 (50)
ANB, mean $\pm$ SD (°)	-2.8 $\pm$ 1.1	-3.0 $\pm$ 1.2	-4.5 $\pm$ 1.6	-4.3 $\pm$ 1.5
Overjet, mean $\pm$ SD (mm)	-2.6 $\pm$ 1.0	-2.8 $\pm$ 1.1	-4.1 $\pm$ 1.4	-4.0 $\pm$ 1.3

Source: supplied study results table.

Table 2. Baseline incidence of speech sound errors

Speech parameter	Facemask	BAMP	Conventional surgery	SFOA
Interdental /s/	18 (90%)	19 (95%)	15 (75%)	16 (80%)
Interdental /z/	17 (85%)	18 (90%)	14 (70%)	15 (75%)
/j/ imprecision	7 (35%)	8 (40%)	7 (35%)	6 (30%)
Rhotacism /r/	6 (30%)	7 (35%)	4 (20%)	5 (25%)
/t/ distortion	5 (25%)	6 (30%)	7 (35%)	6 (30%)
/k/ distortion	3 (15%)	4 (20%)	5 (25%)	4 (20%)
/tj/ distortion	4 (20%)	5 (25%)	5 (25%)	5 (25%)
Any speech error	20 (100%)	20 (100%)	18 (90%)	19 (95%)

Acoustic speech analysis

In addition to perceptual assessment, quantitative acoustic analysis was performed for selected target consonants. The analysis was performed for /s/, /z/, /j/, /t/, /k/, and /tj/.

Two spectral parameters were evaluated:

First spectral moment (M1)

The first spectral moment (M1), representing the spectral centroid or mean frequency distribution of the acoustic energy, was calculated for each selected phoneme.

M1 values were expressed in kHz and reported as mean $\pm$ standard deviation at T1 and T2.

The change in M1 between the two assessment time points was calculated as:

$$\Delta M1 = T2\ M1 - T1\ M1$$

The corresponding 95% confidence interval, P-value and Cohen's d effect size were determined for the pre–post comparison.

The supplied results table reports M1 for /s/, /z/, /ʃ/, /t/, /k/ and /tʃ/ separately for the facemask and BAMP groups.

Second spectral moment (M2)

The second spectral moment (M2), representing spectral spread, was also evaluated for the selected consonants.

M2 values were recorded at T1 and T2 and expressed as mean $\pm$ standard deviation. The mean change, 95% confidence interval, P-value and effect size were calculated for each phoneme and treatment group.

The reported analysis included M2 measurements for /s/, /z/ and /ʃ/ in the supplied results table.

Primary outcome measures

The primary perceptual outcome was the change in incidence of speech sound errors between T1 and T2.

For each target phoneme, the number and percentage of participants demonstrating an articulation error were recorded at both assessment time points.

The following were evaluated:

1. Interdental /s/.
2. Interdental /z/.
3. /ʃ/ imprecision.
4. Rhotacism /r/.
5. /t/ distortion.
6. /k/ distortion.
7. /tʃ/ distortion.
8. Presence of any speech error.

The percentage reduction in speech errors was calculated for each treatment group.

Secondary outcome measures

Secondary outcomes included:

1. Change in incidence of individual phoneme-specific speech errors.
2. Change in the overall proportion of participants demonstrating any speech error.
3. Change in M1 for the selected target consonants.
4. Change in M2 for the selected target consonants.
5. 95% confidence intervals for the acoustic changes.
6. Effect size of the pre–post acoustic changes.
7. Comparison of speech-error reduction among the four treatment modalities.

Four-group comparison

The four treatment groups were compared to determine whether the magnitude of speech improvement differed according to treatment modality.

For each target phoneme, the percentage reduction in speech-error incidence was calculated for:

- growing facemask;
- growing BAMP;
- adult conventional surgery; and
- adult SFOA.

An overall comparison across the four treatment groups was subsequently performed.

The final comparative outcome was expressed as the percentage reduction in speech errors for each phoneme and for the category of any speech error. The supplied results table reports this four-group comparison for all seven target sounds and the overall speech-error category.

Orthodontic and skeletal characteristics

Baseline skeletal and dental characteristics were recorded to describe the study groups.

The variables included:

- ANB angle;
- overjet;
- age; and
- sex.

The mean baseline ANB values were recorded for each treatment group, together with the corresponding overjet measurements. These variables were used for characterization and comparison of the study population rather than as primary speech outcomes.

Data management

Each participant was assigned a unique study identification number.

Demographic, skeletal, speech and acoustic data were recorded in a structured database. Speech recordings were stored using coded identifiers to maintain participant confidentiality.

The speech data were organized according to treatment group and assessment time point before statistical analysis.

Statistical analysis

Statistical analysis was performed using appropriate statistical software.

Categorical speech-error data were expressed as number and percentage [n (%)]. The incidence of each speech error at T1 and T2 was compared within and between treatment groups using appropriate tests for paired and categorical data.

The pre-post changes in the growing facemask and BAMP groups were evaluated separately for each speech characteristic. The corresponding analysis was performed for the conventional surgery and SFOA groups.

For the acoustic variables, continuous data were expressed as mean $\pm$ standard deviation. The pre-post change was calculated for each phoneme, together with the 95% confidence interval and effect size (Cohen's d).

The supplied results demonstrate statistically significant pre-post changes for several M1 and M2 parameters, including /s/ and /z/, with the magnitude of change varying between the facemask and BAMP groups.

For the four-group comparison, the percentage reduction in speech-error incidence was compared across the facemask, BAMP, conventional surgery and SFOA groups.

A P-value <0.05 was considered statistically significant.

RESULTS:

A total of 80 participants were included in the study, with 20 participants in each of the four treatment groups: growing Class III patients treated with facemask and bonded RME, growing Class III patients treated with BAMP and bonded RME, adults treated with conventional orthognathic surgery, and adults treated using the surgery-first orthognathic approach (SFOA). The mean age was 8.1 ± 1.2 years in the facemask group, 8.3 ± 1.3 years in the BAMP group, 23.8 ± 4.2 years in the conventional surgery group, and 24.1 ± 4.5 years in the SFOA group. Baseline ANB and overjet values were more negative in the adult groups, reflecting the greater skeletal and sagittal discrepancy in the skeletally mature patients [Table 1].

Baseline speech characteristics

Speech abnormalities were common before treatment in all four groups. The most frequently observed errors were interdental /s/ and interdental /z/. Interdental /s/ was present in 90% of the facemask group, 95% of the BAMP group, 75% of the conventional surgery group and 80% of the SFOA group. Interdental /z/ was observed in 85%, 90%, 70% and 75% of the respective groups [Table 2].

The remaining errors occurred less frequently. /j/ imprecision was observed in 35% of the facemask group, 40% of the BAMP group, 35% of the conventional surgery group and 30% of the SFOA group. Rhotacism /r/ was present in 30%, 35%, 20% and 25%, respectively. Distortion of /t/, /k/ and /tj/ ranged from 15% to 35% across the four groups [Table 2].

At least one speech error was identified in all participants in both growing groups at baseline. In the adult groups, at least one speech error was present in 90% of the conventional surgery group and 95% of the SFOA group [Table 2]. The distribution of baseline speech errors across the four groups is illustrated in [Figure 1].

Changes following orthopedic treatment in growing patients

Following treatment, a reduction in the frequency of most speech errors was observed in both growing groups. The greatest changes involved the anterior fricatives /s/ and /z/. In the facemask group, interdental /s/ decreased from 90% at T1 to 55% at T2, while in the BAMP group it decreased from 95% to 35%. The corresponding reductions were statistically significant, with a reported $P < 0.001$. For interdental /z/, the prevalence decreased from 85% to 50% in the facemask group and from 90% to 30% in the BAMP group, again with $P < 0.001$ [Table 3].

A smaller reduction was observed for /j/ imprecision, which decreased from 35% to 25% following facemask therapy and from 40% to 20% following BAMP treatment ($P = 0.031$). Changes in rhotacism, /t/ distortion, /k/ distortion and /tj/ distortion were comparatively small and were not statistically significant according to the reported values [Table 3].

Overall, the reduction in speech-error incidence was greater for /s/ and /z/ than for the other assessed consonants. The BAMP group demonstrated a numerically greater reduction than the facemask group for these sounds, with the reduction in /s/ being 60% compared with 35%, and the reduction in /z/ being 60% compared with 35%, respectively

Table 3. Pre- and post-treatment speech-error incidence

Speech error	Facemask T1	Facemask T2	BAMP T1	BAMP T2	P-value
Interdental /s/	18 (90%)	11 (55%)	19 (95%)	7 (35%)	<0.001
Interdental /z/	17 (85%)	10 (50%)	18 (90%)	6 (30%)	<0.001
/j/ imprecision	7 (35%)	5 (25%)	8 (40%)	4 (20%)	0.031
Rhotacism /r/	6 (30%)	5 (25%)	7 (35%)	5 (25%)	0.418
/t/ distortion	5 (25%)	4 (20%)	6 (30%)	3 (15%)	0.214
/k/ distortion	3 (15%)	3 (15%)	4 (20%)	2 (10%)	0.582
/tj/ distortion	4 (20%)	3 (15%)	5 (25%)	2 (10%)	0.317

FIGURE 2:

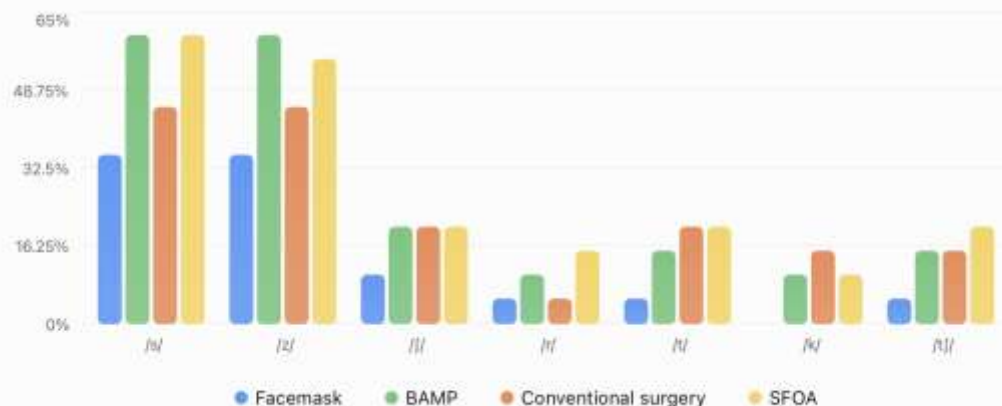


Figure 2. Reduction in speech-error incidence following treatment

Percentage reduction in speech-error incidence following treatment across the four Class III treatment groups. This figure corresponds to the comparative reductions reported in the supplied four-group analysis. The greatest reductions were observed for /s/ and /z/, particularly following BAMP and SFOA treatment.

Changes following orthognathic treatment in adults

A similar improvement in speech-error incidence was observed after orthognathic treatment. In the conventional surgery group, interdental /s/ decreased from 75% preoperatively to 30% postoperatively, whereas in the SFOA group it decreased from 80% to 20%. The reported between-group P-value was 0.041. Interdental /z/ decreased from 70% to 25% in the conventional surgery group and from 75% to 20% in the SFOA group, with a reported P = 0.049 [Table 4].

For /ʃ/ imprecision, the prevalence decreased from 35% to 15% after conventional surgery and from 30% to 10% after SFOA. The corresponding between-group P-value was 0.312. Rhotacism decreased from 20% to 15% and from 25% to 10%, respectively (P = 0.624) [Table 4].

The prevalence of /t/ distortion decreased from 35% to 15% in the conventional surgery group and from 30% to 10% in the SFOA group. For /k/ distortion, the corresponding reductions were from 25% to 10% and from 20% to 10%, respectively. /tʃ/ distortion decreased from 25% to 10% following conventional surgery and from 25% to 5% following SFOA. None of these latter between-group comparisons reached the reported level of statistical significance [Table 4].

The percentage reductions across the four treatment modalities are summarized in [Figure 2]. The greatest reductions were consistently observed for /s/ and /z/, whereas the changes in /r/, /k/ and /tʃ/ were more modest.

Table 4. Quantitative acoustic changes in M1 and M2

Phoneme	Group	ΔM1	P	Cohen's d	ΔM2	P	Effect size
/s/	Facemask	-0.48	<0.001	0.68	-0.29	<0.001	0.73
/s/	BAMP	-0.76	<0.001	1.01	-0.49	<0.001	1.25
/z/	Facemask	-0.37	0.002	0.55	-0.22	0.002	0.59
/z/	BAMP	-0.65	<0.001	0.91	-0.41	<0.001	1.12

/j/	Facemask	-0.16	0.036	0.34	-0.12	0.021	0.40
/j/	BAMP	-0.37	<0.001	0.78	-0.29	<0.001	0.97

Acoustic analysis of speech production

Quantitative acoustic analysis was performed for selected consonants in the growing treatment groups. The first spectral moment (M1) decreased after treatment for all six evaluated consonants in both the facemask and BAMP groups [Table 5].

For /s/, M1 decreased from 5.82 ± 0.74 to 5.34 ± 0.68 kHz following facemask treatment, corresponding to a mean change of -0.48 kHz (95% CI, -0.71 to -0.25; $P < 0.001$; Cohen's $d = 0.68$). Following BAMP treatment, M1 decreased from 5.91 ± 0.79 to 5.15 ± 0.65 kHz, with a larger mean change of -0.76 kHz (95% CI, -1.02 to -0.50; $P < 0.001$; Cohen's $d = 1.01$) [Table 5].

For /z/, M1 decreased by 0.37 kHz in the facemask group and by 0.65 kHz in the BAMP group. Both changes were statistically significant, with $P = 0.002$ and $P < 0.001$, respectively. The corresponding effect sizes were 0.55 and 0.91 [Table 5].

A significant reduction was also observed for /j/, with M1 decreasing by 0.16 kHz in the facemask group ($P = 0.036$; $d = 0.34$) and by 0.37 kHz in the BAMP group ($P < 0.001$; $d = 0.78$). Similar reductions were observed for /t/, /k/ and /tʃ/, with the magnitude of change consistently greater in the BAMP group [Table 5].

The second spectral moment (M2) also decreased following treatment. For /s/, M2 decreased by 0.29 in the facemask group and 0.49 in the BAMP group, with both comparisons showing $P < 0.001$. The corresponding effect sizes were 0.73 and 1.25, respectively.

For /z/, M2 decreased by 0.22 in the facemask group ($P = 0.002$; effect size = 0.59) and by 0.41 in the BAMP group ($P < 0.001$; effect size = 1.12). For /j/, the respective reductions were 0.12 ($P = 0.021$; effect size = 0.40) and 0.29 ($P < 0.001$; effect size = 0.97).

Taken together, the acoustic findings showed a consistent reduction in both M1 and M2 following treatment, with larger numerical changes and generally larger effect sizes in the BAMP group [Tables 5].

Table 5. Changes in spectral spread (M2) of target consonants following treatment

Phoneme	Group	T1 M2, mean $\pm$ SD	T2 M2, mean $\pm$ SD	Mean change	95% CI	P-value	Effect size
/s/	Facemask	2.31 ± 0.42	2.02 ± 0.37	-0.29	-0.43 to -0.15	<0.001	0.73
/s/	BAMP	2.38 ± 0.45	1.89 ± 0.34	-0.49	-0.65 to -0.33	<0.001	1.25
/z/	Facemask	2.16 ± 0.39	1.94 ± 0.35	-0.22	-0.35 to -0.09	0.002	0.59
/z/	BAMP	2.22 ± 0.41	1.81 ± 0.32	-0.41	-0.56 to -0.26	<0.001	1.12

/j/	Facemask	1.84 ± 0.31	1.72 ± 0.29	-0.12	-0.22 -0.02	to	0.021	0.40
/j/	BAMP	1.87 ± 0.33	1.58 ± 0.27	-0.29	-0.41 -0.17	to	<0.001	0.97

Overall comparison of treatment modalities

When the percentage reduction in speech-error incidence was compared across the four treatment modalities, the largest reductions were observed for interdental /s/ and /z/. The reduction in /s/ was 35% with facemask therapy, 60% with BAMP, 45% with conventional surgery and 60% with SFOA (overall $P < 0.001$). For /z/, the corresponding reductions were 35%, 60%, 45% and 55%, respectively (overall $P < 0.001$) [Table 5; Figure 2].

For /j/, error reduction was 10% in the facemask group and 20% in each of the BAMP, conventional surgery and SFOA groups ($P = 0.041$). The reduction in /r/ errors was 5%, 10%, 5% and 15%, respectively, without a statistically significant overall difference ($P = 0.218$) [Table 5].

For /t/, the reduction was 5% with facemask, 15% with BAMP, and 20% with both conventional surgery and SFOA ($P = 0.031$). The corresponding reductions for /k/ were 0%, 10%, 15% and 10% ($P = 0.087$), while those for /tj/ were 5%, 15%, 15% and 20% ($P = 0.062$) [Table 5; Figure 2].

When the presence of any speech error was considered, the overall reduction was 25% in the facemask group, 55% in the BAMP group, 40% in the conventional surgery group and 55% in the SFOA group, with a reported overall $P < 0.001$ [Table 5; Figure 2].

Overall, the results indicate that speech-error incidence decreased following all four treatment approaches, with the most pronounced changes involving the /s/ and /z/ sounds. Among the growing patients, the BAMP group demonstrated greater reductions in the reported speech-error measures than the facemask group. Among adults, SFOA showed numerically greater reductions for several speech sounds, although statistically significant between-treatment differences were reported only for /s/ and /z/ in the adult comparison. The acoustic analysis in the growing groups also demonstrated larger changes in M1 and M2 following BAMP treatment.

DISCUSSION

Speech production depends on the coordinated interaction of the jaws, tongue, lips, teeth and surrounding oral structures. Changes in the maxillomandibular relationship can therefore modify the articulatory environment and influence the production of consonants, particularly sounds requiring precise anterior oral constriction [12]. The high frequency of speech errors observed at baseline in the present study, particularly for /s/ and /z/, is consistent with previous reports describing sibilant consonants as commonly affected in patients with dentofacial skeletal discrepancies [13]. Similar observations have been reported in patients undergoing orthognathic surgery, in whom /s/ and /z/ were among the most frequently affected sounds before treatment [14].

The present findings also need to be interpreted in the context of the complex relationship between occlusion and speech. Although correction of a skeletal discrepancy can modify the anatomical environment in which articulation occurs, speech is also a learned motor behaviour and individuals may develop compensatory articulatory patterns. Consequently, the presence of a skeletal Class III relationship does not imply that every patient will have a clinically relevant speech disorder, and correction of the skeletal discrepancy cannot be assumed to produce complete speech normalization in every patient [15].

Growing patients: facemask versus BAMP

The most notable finding among the growing patients was the greater numerical reduction in /s/ and /z/ errors following BAMP compared with facemask therapy. The reduction in /s/ errors was 60% in the BAMP group compared with 35% in the facemask group, while the corresponding reductions for /z/ were also 60% and 35%, respectively [16]. This difference is clinically interesting because both treatment protocols were directed toward correction of the underlying Class III discrepancy, but BAMP uses skeletal anchorage and is intended to increase the orthopedic component of maxillary protraction.

The acoustic findings provided additional evidence of changes in speech production following treatment. M1 decreased for all six evaluated consonants in both growing groups, with larger numerical reductions in the BAMP group. This is particularly relevant because previous Class III research has demonstrated measurable spectral differences in stop, fricative and affricate consonants, supporting the use of objective acoustic measurements in addition to perceptual assessment [17].

The reduction in M2 followed a similar pattern, with larger changes in the BAMP group for /s/, /z/ and /ʃ/. Spectral-moment measurements can provide information that may not be apparent from a simple correct/incorrect perceptual classification, making them potentially useful for detecting subtler changes in articulation. Nevertheless, the present findings should be interpreted as evidence of changes in acoustic speech characteristics, rather than proof that the acoustic changes necessarily represent improved overall intelligibility[18].

An additional consideration in the growing groups is the use of bonded RME in both treatment protocols. Rapid maxillary expansion itself can influence speech because it changes the dimensions and relationships of the oral and nasal cavities. A recent systematic review found that RME can alter speech parameters, including fricative characteristics, although the available evidence was limited and heterogeneous [19]. Therefore, some of the observed acoustic changes in the present study may reflect the combined effect of skeletal correction and expansion rather than maxillary protraction alone.

This is particularly important when interpreting the apparently greater changes following BAMP. The present study does not establish that skeletal anchorage itself directly produced the greater speech improvement. Differences in the amount of skeletal advancement, changes in overjet, individual adaptation, baseline speech characteristics and the timing of post-treatment assessment may all contribute to the observed differences. The greater numerical improvement observed with BAMP should therefore be considered a finding that warrants further investigation rather than evidence that BAMP should be prescribed specifically to treat speech abnormalities[20].

Changes following orthognathic surgery

The adult groups demonstrated a similar overall reduction in speech-error incidence following orthognathic correction. The most pronounced changes again involved /s/ and /z/, whereas the changes in /r/, /k/ and /tʃ/ were smaller. This pattern is consistent with previous clinical observations that sibilant consonants are particularly susceptible to articulation changes in patients with severe skeletal discrepancies [21].

A prospective study of skeletal Class III patients undergoing Le Fort I maxillary advancement combined with mandibular setback found that articulation errors did not change significantly during the first 3–6 months following surgery but decreased substantially by approximately 9 months, with the improvement maintained through 18 months. This is particularly relevant when interpreting postoperative speech because the timing of assessment can substantially influence the apparent treatment effect.

Earlier longitudinal work also demonstrated that articulation may improve after orthognathic surgery without formal speech intervention, although some errors may persist or recur during longer follow-up. These observations support the concept that postoperative speech adaptation is a dynamic process rather than an immediate consequence of surgical repositioning of the jaws.

The broader literature, however, remains inconsistent. A critical review of studies evaluating cranio-maxillofacial osteotomies reported considerable variation in the effects of surgery on speech and velopharyngeal function, with some studies demonstrating improvement and others finding little or no change. A systematic review and meta-analysis published more recently similarly concluded that orthognathic surgery may have limited effects on several voice-related parameters, while fricative distortions, particularly /s/ and /z/, were among the most frequently reported preoperative articulation abnormalities [22].

Thus, the reduction in /s/ and /z/ errors observed in the present adult groups is biologically plausible and supported by previous literature, but the results should not be interpreted as evidence that orthognathic surgery universally normalizes speech. Individual adaptation, baseline articulatory patterns, magnitude of surgical movement and the timing of postoperative assessment are likely to influence the final outcome.

Conventional surgery versus surgery-first approach

The present study showed numerically greater reductions in several speech errors following SFOA than conventional orthodontic–orthognathic treatment. However, statistically significant differences between the two adult approaches were observed only for /s/ and /z/. Therefore, the present findings do not provide sufficient evidence to conclude that SFOA is generally superior to conventional treatment for speech.

This distinction is important because the principal difference between the two approaches is the sequence of treatment, rather than the fundamental objective of correcting the skeletal discrepancy. A systematic review of the surgery-first approach reported shorter overall treatment duration but emphasized substantial heterogeneity in treatment protocols and outcome assessment [23].

A subsequent systematic review of systematic reviews similarly concluded that SFOA may be a reasonable alternative to conventional treatment, with shorter treatment duration reported consistently, although the evidence for several outcomes was limited by the methodological quality and heterogeneity of the available systematic reviews. More recent evidence has continued to emphasize that differences in skeletal stability between SFOA and conventional treatment remain dependent on the specific treatment protocol, follow-up period and outcome measured [24].

Importantly, most of this literature has concentrated on skeletal stability, treatment duration, occlusal outcomes and quality of life rather than speech. Therefore, the speech findings from the present investigation provide an additional functional perspective, but they should not be used alone to recommend one surgical sequence over another.

Perceptual and acoustic findings

A strength of the present study is that speech was evaluated using both perceptual assessment and quantitative acoustic measurements. The perceptual analysis demonstrated a reduction in the frequency of identifiable speech errors, particularly for /s/ and /z/, while the acoustic analysis demonstrated changes in M1 and M2. The convergence of these findings provides stronger evidence of a change in speech production than would be obtained from either assessment method alone.

The use of acoustic analysis is also supported by previous Class III research in which spectral moment analysis identified differences in the frequency distribution of consonantal sounds between Class III patients and reference subjects. However, acoustic measurements should not be interpreted in isolation. Changes in spectral characteristics do not necessarily translate directly into improved speech intelligibility, and perceptual accuracy and communicative intelligibility represent related but distinct outcomes.

This distinction is important in light of the recent longitudinal Class III study by Lal et al., in which articulation errors decreased substantially after orthognathic surgery while overall speech intelligibility did not demonstrate a statistically significant improvement. Therefore, the present findings support a change in speech production but should not be interpreted as evidence of improved overall communication unless intelligibility is assessed separately [25].

Clinical implications

The findings suggest that speech can be considered as an additional functional outcome when evaluating patients with skeletal Class III malocclusion. This may be particularly relevant in patients with pronounced anterior skeletal and dental discrepancies in whom the articulatory environment is substantially altered.

At the same time, patients should be counselled that orthodontic or orthognathic correction may change the anatomical conditions for speech but does not guarantee complete resolution of an established articulation pattern. The contemporary literature emphasizes that patients can develop compensatory speech patterns in response to dentofacial morphology and that a direct cause-and-effect relationship between malocclusion and speech cannot always be demonstrated.

For growing patients, the greater numerical improvement observed following BAMP is noteworthy. However, the primary indication for BAMP remains correction of the underlying skeletal Class III discrepancy, and the present findings should not be interpreted as establishing speech improvement as an independent indication for skeletal-anchored maxillary protraction.

The same principle applies to RME. Because RME itself may temporarily influence speech production, particularly fricative and vowel characteristics, speech assessments in patients receiving RME-containing protocols should ideally be interpreted with awareness of the appliance-related component. This is particularly relevant to the present study because both growing treatment protocols incorporated bonded RME.

For adult surgical patients, postoperative counselling should also emphasize that speech adaptation may continue after surgery. Previous longitudinal evidence suggests that articulation can continue to change for several months following skeletal repositioning, making the timing of postoperative assessment an important consideration.

Limitations

Several limitations should be considered when interpreting the present findings. First, the perceptual speech assessment was performed by a single investigator rather than by an independent speech-language pathologist. Although intra-examiner reliability can reduce concerns regarding scoring consistency, perceptual assessment remains susceptible to examiner-related bias.

Second, speech is influenced by language, age, individual phonetic characteristics and previous speech experience. The literature on orthodontic appliances also demonstrates that appliances themselves can temporarily alter speech, with sounds such as /s/, /z/, /t/, /d/, /r/ and /j/ reported to be susceptible to distortion [23-27]. This is relevant when interpreting speech changes during orthodontic treatment and emphasizes the importance of standardized assessment timing.

Third, the four groups differed in skeletal maturity and treatment modality. Consequently, the adult and growing cohorts should not be regarded as directly interchangeable populations. The comparisons are more appropriately interpreted within the growing and adult strata, followed by an exploratory comparison across treatment approaches.

Fourth, acoustic analysis was restricted to selected consonants and was performed in the growing groups. The acoustic findings therefore cannot be directly extrapolated to the adult surgical groups.

Finally, postoperative adaptation remains an important consideration. Earlier research has demonstrated that speech outcomes may vary at different postoperative time points [13], while systematic reviews have highlighted substantial heterogeneity in speech-assessment methods and follow-up periods [12]. Future studies should therefore incorporate standardized longitudinal follow-up and, ideally, independent assessment by qualified speech-language professionals.

Overall interpretation

The present study demonstrated that treatment of skeletal Class III malocclusion was accompanied by measurable changes in speech production in both growing and adult patients. The most consistent perceptual changes involved /s/ and /z/, while acoustic analysis demonstrated changes in M1 and M2 across several evaluated consonants.

Among growing patients, BAMP was associated with greater reductions in speech-error incidence and larger numerical changes in M1 and M2 than facemask therapy. This finding is clinically interesting but should be interpreted cautiously because the present study does not establish that BAMP itself caused the greater speech improvement.

Among adults, both conventional orthognathic treatment and SFOA were associated with reductions in speech-error incidence, although the available findings do not establish a general speech advantage for either surgical sequence. Overall, the results support consideration of speech as an additional functional outcome of Class III correction, while recognizing that correction of the skeletal discrepancy and normalization of an established speech pattern are related but distinct processes.

Conclusion

Treatment of skeletal Class III malocclusion was associated with measurable improvements in speech sound production in both growing and adult patients, with the greatest reductions observed for /s/ and /z/. Among growing patients, BAMP demonstrated greater numerical reductions in speech errors and larger acoustic changes in M1 and M2 than facemask therapy, while both conventional orthognathic treatment and SFOA were associated with improvement in adults. Overall, these findings suggest that correction of the skeletal and dentoalveolar relationship may positively influence speech production and support the inclusion of speech assessment as an additional functional outcome in the comprehensive management of skeletal Class III malocclusion.

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