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ARTICULATION ERRORS IN MALAYALAM SPEAKING CHILDREN WITH HEARING IMPAIRMENT WHO USE DIGITAL HEARING AIDS: AN EXPLORATORY STUDY

Contributions:
A Study design/planning
B Data collection/entry
C Data analysis/statistics
D Data interpretation
E Preparation of manuscript
F Literature analysis/search
G Funds collection

N. Sreedevi[A-G], Anusmitha Mathew[A-F]

Department of Speech-Language Sciences, All India Institute of Speech and Hearing, Mysuru, India

Corresponding author: N. Sreedevi, Department of Speech-Language Sciences, All India Institute of Speech and Hearing, Manasagangothri, 570006, Mysuru, India; email: sreedevi@aiishmysore.in

Abstract

Background: Speech sound errors are often exhibited by children with hearing impairment. Articulatory error pattern analyses show a tendency towards vowel substitutions and consonant omissions. There is a dearth of literature on the articulatory characteristics of Indian children who use digital hearing aids. Such information is crucial for speech language pathologists in correcting articulation errors. Hence this study examined the nature of speech sound errors in Malayalam speaking children with hearing impairment who use digital hearing aids.

Material and methods: A total of 7 monolingual Malayalam speaking children aged 3–7 years who were diagnosed as having spoken-language disorder secondary to congenital hearing impairment (>70 dB HL bilaterally) were analysed. Frequently misarticulated vowels and consonants were ascertained from recorded speech samples. Additional error analysis was performed based on error type and the place, manner, and voicing features of the consonants.

Results: The short vowel /u/ and long vowel /i:/ were found to be the most frequently misarticulated vowels. The most frequently misarticulated consonants were trills (/r/), affricates (/ʤ/, /ʧ/), and fricatives (/ʂ/, /ʃ/). Substitution errors were the most common error type. Place–manner errors and place errors were more frequent than other types of errors.

Conclusions: Targeting frequently misarticulated speech sounds supports effective intervention, leading to improved speech intelligibility in children with hearing impairment.

Key words: vowels • hearing impairment • consonants • articulatory error • digital hearing aids

ANALIZA BŁĘDÓW ARTYKULACJI POPEŁNIANYCH PRZEZ POSŁUGUJĄCE SIĘ JĘZYKIEM MALAJALAM DZIECI Z NIEDOSŁUCHEM UŻYWAJĄCE CYFROWYCH APARATÓW SŁUCHOWYCH: BADANIE WSTĘPNE

Streszczenie

Wprowadzenie: Dzieci z niedosłuchem często popełniają błędy w artykulacji. Analiza wzorca błędów artykulacyjnych pokazuje tendencję do zamieniania samogłosek i opuszczania spółgłosek. W literaturze brakuje publikacji na temat charakterystyki artykulacji hinduskich dzieci używających cyfrowych aparatów słuchowych. Informacja taka jest niezbędna dla logopedów zajmujących się korygowaniem błędów wymowy. Dlatego niniejsze badanie analizuje charakterystykę błędów artykulacji popełnianych przez posługujące się językiem malajalam dzieci z niedosłuchem używające cyfrowych aparatów słuchowych.

Materiał i metody: W badaniu wzięło udział 7 dzieci mówiących tylko w języku malajalam, w wieku 3–7 lat, z orzeczeniem zaburzeń wymowy spowodowanych wrodzonym niedosłuchem (>70 dB HL obustronnie). Na podstawie nagranych próbek mowy ustalono, które samogłoski i spółgłoski są często nieprawidłowo wymawiane. Przeprowadzono dodatkowo analizę błędów na podstawie typu błędu oraz miejsca, sposobu i charakterystyki realizacji spółgłosek.

Wyniki: Krótka samogłoska /u/ i długa samogłoska /i:/ były najczęściej nieprawidłowo wymawiane. Najczęściej nieprawidłowo wymawianymi spółgłoskami były spółgłoski drżące (/r/), zwarto-szczelinowe (/ʤ/, /ʧ/) i szczelinowe (/ʂ/, /ʃ/). Najczęstszym typem błędu była substytucja. Częściej niż inne typy błędów występowały błędy związane z jednocześnie niewłaściwym miejscem i sposobem realizacji głoski oraz samym miejscem realizacji głoski.

Wnioski: Ukierunkowanie pracy terapeutycznej na te głoski, które są najczęściej nieprawidłowo artykułowane, sprawi, że terapia będzie skuteczniejsza i poprawi zrozumiałość mowy dzieci z zaburzeniami słuchu.

Słowa kluczowe: samogłoski • niedosłuch • spółgłoski • częstość występowania błędów artykulacji • cyfrowe aparaty słuchowe • typy błędów artykulacji

Introduction

Children with hearing impairment (HI) are at greater risk of speech sound disorder (SSD). Even though isolated production of several phonemes are accurate in HI children, they find it challenging to coalesce these phonemes into running speech, resulting in reduced speech intelligibility. Intelligible speech is a vital skill to be able to interact with the world at large [1]; it is essential not only for basic communication but also for social and emotional development [2]. Speech intelligibility is known to correlate with the level of aided hearing [3]. Remarkable development of segmental features has been reported in HI children after being fitted with suitable hearing aids [4]. Errors in vowel and consonant production – predominantly substitutions, distortions, and omissions [5–7] – are demonstrated by children with HI. Developmentally, these children fail to attain the 90% criterion for a majority of sounds other than vowels and some of the bilabial stop consonants [8].

Compared to consonants, vowel production has been reported to be better in the speech of HI children [9]. The acoustic and articulatory properties of the vowels derive from the relative ease of vowel production in children with HI; nevertheless, studies exploring the articulatory properties of vowels are sparse compared to their acoustic properties [7,10,11].

Despite the relative ease of vowel production, vowel errors are not uncommon in the speech of HI children. The predominant vowel errors are neutralization to a central vowel, tense/lax alterations (/i/–/I/, /u/–/U/), substitution among nearby vowels in the vowel quadrilateral, and inappropriate or diphthongization of monophthongs [8,12–14]. Vowel errors are different at different word positions in children with HI [12]. In the word initial position, addition errors dominate over other type of errors, whereas in the word medial position, substitution errors (especially with a mid-central vowel /ə/) are very common. Vowel errors correspond to a reduced speech intelligibility in children with HI [15,16].

Although children with HI are described to be less accurate than children with normal hearing (NH) in consonant production, they both follow a typical developmental pattern [17]. In the literature on the acquisition of consonants in HI children, a predominance of early-appearing stops, glides, nasals, and mid-level stops has been reported [18]. Fricatives and affricates are uncommon in the early phonological acquisition stages. Wiggin et al. [19] reported that 50% of English-speaking children with HI produce all the consonants correctly by around 7 years of age.

Errors in consonant production (distortions, substitutions, omissions, and additions) are phonetic errors at the segmental level. In children with HI, omission and substitution errors are most detrimental to the overall speech intelligibility [11,18,20]. According to Penã-Brooks and Hedge [21], distortion errors impact only one sound feature and tend to marginally influence the overall speech intelligibility. Substitution errors occur more in the word initial position and more visible consonants are used for substitution [11,22]. Electropalatographic findings suggest that stops are substituted for other classes of sounds, while fricatives are the most substituted sounds [23,24]. Manner and voicing errors dominate over place errors of articulation [14,25]. Owing to the perceptual deficits arising from HI, voicing errors are common for stops and fricatives [20].

Phonological acquisition in children is shaped by the frequency of occurrence of each speech sound or phoneme in their particular language [26]. There is a plethora of literature on the frequently occurring phonemes in various languages [27–30]. In languages such as Cantonese, Mandarin, Italian, German, and American English, consonants predominate over vowels in terms of their frequency of occurrence [30]; likewise, studies of Indian languages yield similar results [31–35]. In a multicultural and multilingual country like India, in order to develop various speech materials for assessment and management of children with communication disorders, it is essential to be aware of the relative occurrence of phonemes in each language [35].

Only a handful of studies have examined the frequency of occurrence of speech sound errors in Indian languages when a communication disorder exists. Malayalam is a Dravidian language spoken in the southern region of India. Rofina [36] reported that Malayalam-speaking children with speech sound disorder (SSD) frequently substitute /k/ with /t/; /g/ with /k/; /r/ with /l/ or /ʈ/; and retroflex with cognate dentals. Similar findings have also been reported in a replication of this study among children speaking Kannada (a Dravidian language spoken in the southwestern region of India), with the exception of the frequent substitution of /ʃ/ with /s/ [37].

Joy [12] explored the articulatory errors of all phonemes at different word positions in Malayalam-speaking children who used a cochlear implant (CI). Substitution errors were the major consonant error type according to SODA (substitution, omission, distortion, addition) analysis. Place, manner, and voicing analysis (PVM) was suggestive of frequent place errors rather than manner errors. Bilabials were the most correctly produced, with the order of accuracy, based on the place of articulation, being retroflex < alveolar < dental < labiodental < palatals < velars < bilabials. Concerning the manner of articulation, glides were the most accurately produced, with the order of accuracy being approximants /ɻ/ < trill/flap < fricative < affricate < stops < laterals < nasals < glides. Voicing feature analysis revealed prominent devoicing errors among voiced aspirated phonemes. With respect to the position, at the word initial position, stops and nasals were produced with ease, whereas fricatives, affricates, and approximants were better produced in word medial position.

Significantly more phonetic and phonological disorders are seen in children using hearing aids (HAs) than those using CIs [38]. Speech intelligibility was reported to improve from 0% to 40% in CI users after about 3.5 years of usage. In contrast, HA users had an average score of only 22% [39,40]. Recently, there have been attempts to outline the articulatory errors of children using CIs [12,19,41]. In the 1980s, there were reports seeking to profile the speech sound characteristics of children using analogue HAs. However, in children using a digital HA, there is a shortage in the Indian literature examining frequently misarticulated speech sounds and error types. Currently available digital HAs are on a par with CIs in terms of signal processing quality [42,43]. Hence, the need arises to investigate the articulatory characteristics of digital HA users. Speech production accuracy and intelligibility can be improved if treatments are directed towards training the most frequently mistaken speech features [44]. The present study aimed to investigate the frequently misarticulated speech sounds in Malayalam speaking HI children who used digital hearing aids. The specific objectives of the study were: (a) to identify the frequently misarticulated speech sounds (consonants and vowels); and (b) to describe the errors in such children rehabilitated using digital hearing aids based on SODA and PVM analyses.

Material and methods

Participants

Initially, a total of 10 monolingual Malayalam speaking children diagnosed as spoken-language disorder secondary to congenital hearing impairment (> 70 dB HL bilaterally) in the age range of 3–7 years were considered for the study. The inclusion criteria included a minimum language age greater than 3 years. All were attending speech language therapy services, but all had articulation errors of vowels and consonants with poor speech intelligibility. All participants used suitable hearing aids binaurally based on the configuration of hearing loss as certified by an audiologist. The aided audiometric thresholds of all participants were within the speech spectrum. Children with any associated/co-morbid conditions such as cognitive or motor deficits were excluded from the study. However, due to subject related factors and poor quality of recording, samples of 3 children were not considered suitable for the analysis of this study, leaving 7 Malayalam speaking HI children using digital HAs. All 7 participants were active digital hearing aid users, and the current study did not consider participants using cochlear implants. In the Indian context there are more hearing aid users compared to those using CIs.

The participants were recruited by a convenient sampling approach. The study was approved by the Ethical Board of the All India Institute of Speech and Hearing, Mysuru, India. Before the study, written consent was obtained from the parents of each participant and no ethical conflicts were present.

Procedure

The study followed a descriptive design. The language age of the participants was assessed by administering the Assessment Checklist for Speech and Language Skills (ACSLS) [45], an Indian norm-based language test that examines the receptive and expressive language of children up to 7 years of age. To rule out motor, oro-motor, or any cognitive impairments, another Indian norm-based test, the Developmental Screening Test (DST) [46] was utilized.

Articulatory assessment and transcription

The articulatory skills of the 7 participants were evaluated using the Malayalam Articulation Test – Revised (MAT-R) [47] through spontaneous picture naming of 100 stimulus words. Due to the pandemic situation, the assessment was carried out in tele-mode using Zoom or Google Meet platforms. The time taken to complete the assessment varied across participants and ranged from 1 to 1.5 hours. To minimise fatigue and inattention, the entire assessment included two or three sittings for each participant. The recorded assessment sessions were listened to and transcribed using the International Phonetic Alphabet [48].

Data analysis

Malayalam is a Dravidian language spoken by the native people of Kerala in South India. It has 11 monophthongs and 52 consonants. Vowel length is phonemic and all the vowels have minimal pairs (e.g. /paʈʈŭ/ "silk", /pa:ʈʈŭ/ "song"; /koɖi/ "flag", /ko:ɖi/ "crore"; /aɖa/, "snack", /a:ɖa/, "dress"). As in other Dravidian languages, the retroflex series are true subapical consonants, in which the underside of the tongue contacts the roof. Other than stop retroflex (ʈ,ɖ), there are lateral, trill, and nasal retroflex (ɭ, r, ɳ). Consonants in word final position are minimal in Malayalam. The vowel and consonant errors were analysed and documented from the 100 words of the administered test. From the speech sample obtained, each phoneme was assessed in a variety of contexts. The following phonemes in Malayalam were analysed: 6 short vowels (/a/, /i/, /u/, /e/, /o/, and /ə/); five long vowels (/a:/, /i:/, /u:/, /e:/, and /o:/); and 13 consonants. The consonants were /k/, /g/ (unvoiced and voiced velar stops); /tʃ/, /ʤ/ (unvoiced and voiced palatal affricates); /ʈ/, /ɖ/ (unvoiced and voiced alveolar stops); /s/ (alveolar fricative); /ʂ/ (retroflex fricative); /ʃ/ (palatal fricative); /ɾ/ (alveolar flap); /r/ (retroflex trill); /ɳ/ (retroflex nasal); and /ɭ/ (retroflex lateral). The vowels were tested in a total of 95 contexts for word initial position and 108 for word medial position. The consonants were tested in 28 contexts for word initial position, 52 for word medial position, and 3 for word final position. The number of error productions were calculated for every vowel and consonant for each participant to determine the frequently misarticulated speech sounds. Every stimulus word with an error production of the target phoneme received a score of '0', whereas correct productions were scored '1'. In this way, the percentage of errors for a particular phoneme for each participant was determined.

Following this, a 20% criterion [49] was used to consider a phoneme an error production; that is, if a phoneme was incorrect in 1 out of 5 target words, it was considered an articulation error. To identify the frequently misarticulated vowel/consonants, the percentage of participants with more than 20% error production for each phoneme was documented. Qualitative analysis was done for the transcribed data. Articulatory skills were analysed in detail for substitution, omission, distortion, and addition (SODA) errors as well as for place, voice, and manner errors (PMV). Qualitative analysis was carried out separately for each vowel and consonant to determine the frequency of each type of error.

Qualitative analysis of vowels

Both short and long vowels were analysed for articulatory deviations. These errors are described as:

1) Substitution: substitution of one vowel for another; e.g., /pu:va/ for /pu:və/ (meaning "flower"), where /a/ is substituted for /ə/.

Table 1. Mean percentage errors for vowels and consonants

Short vowels	Mean error (%)	Long vowels	Mean error (%)	Consonants	Mean error (%)
/a/	12.90	/a:/	4.00	/k/	22.85
/i/	11.03	/i:/	10.71	/g/	57.14
/u/	16.88	/u:/	8.16	/tʃ/	65.30
/e/	9.52	/e:/	9.52	/ʤ/	77.14
/o/	14.28	/o:/	5.95	/ʈ/	35.71
/ə/	1.19			/ɖ/	50.79
				/s/	57.14
				/ʂ/	66.66
				/ʃ/	64.28
				/ɾ/	59.74
				/r/	90.90
				/ɳ/	44.89
				/ɭ/	47.61

2) Omission: deletion of one phoneme/syllable; e.g., /teppə/ for /ʧeɾuppə/ (sandals), wherein /u/ is omitted in the medial position.
3) Distortion: when the target vowel pronounced is a non-Malayalam sound.
4) Addition: addition of a sound to the target sound; e.g., /konnə/ for /onnə/ (meaning "one"), where /k/ is added in initial position.

For each vowel, the number and percentage of errors were calculated. Further, vowel substitution errors were analysed in detail to identify different substitutions of target vowels.

Qualitative analysis of consonants

For every consonant, the number and percentage of SODA errors were calculated. Following this, to determine the substitution errors of consonants, PMV analysis was carried out to find the changes in place, manner, and voicing features. Consonant errors were itemized under specific places and manners of articulation in word initial and word medial positions. The percentage of substitutions for each phoneme and the specific phoneme substituted was recorded. The overall percentage of substitution for each place of articulation (POA) and manner of articulation (MOA) were calculated. Likewise, the percentage of voicing errors were computed in word initial and word medial positions based on the occurrence of the respective phonemes.

Results

The descriptive analysis of articulatory errors of the participants with hearing impairment using digital hearing aids are reported under two headings: frequently misarticulated speech sounds, and type of errors of vowels and consonants.

Frequently misarticulated speech sounds

According to the 20% criteria for error analysis, 3 of the participants made mistakes in both short vowel /u/ and long vowel /u:/. The order of frequently misarticulated short vowels from the most erroneous to the least erroneous were /u/ > /o/ > /a/ > /i/ > /e/ > /ə/. Likewise, frequently misarticulated long vowels were, in order /i:/ > /e:/ > /u:/ > /o:/ > /a:/.

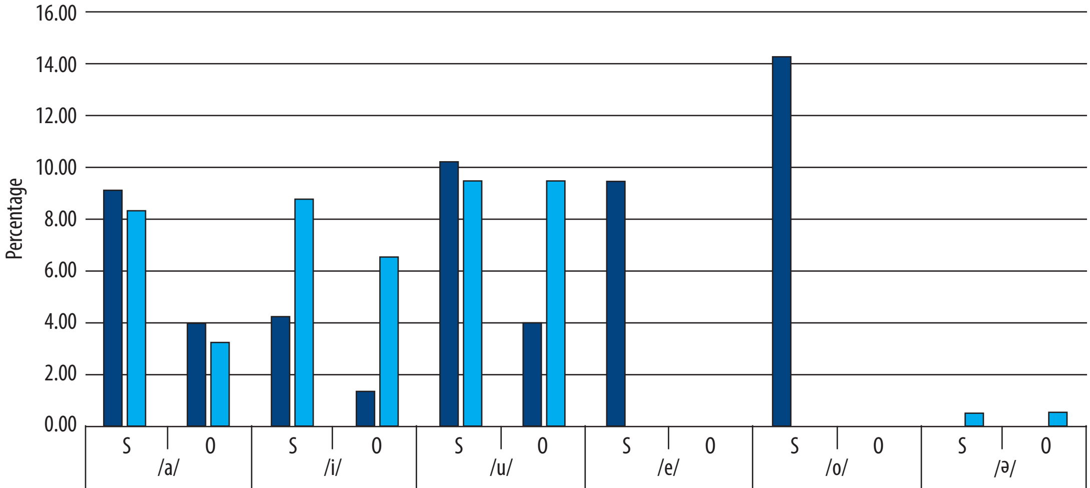
All 7 participants demonstrated frequent misarticulation of retroflex trill /r/ and affricate /ʤ/. The order of frequently misarticulated consonants was /r/ > /ʤ/ > /ʂ/ > /ʧ/ > /ʃ/ > /ɾ/ > /g/ > /s/ >/ɖ/ > /ɭ/ > /ɳ/ > /ʈ/ > /k/. Retroflex trill /r/ was the most affected phoneme while the velar stop /k/ was the least affected. **Table 1** presents the percentages of mean errors for short and long vowels and the consonants.

Type of errors

The vowels were analysed on the basis of SODA errors.

Short vowel errors

As shown in **Figure 1**, higher occurrence of substitution errors was observed in the articulatory analysis of short vowels than omissions. Addition and distortion errors were not observed. Vowels were misarticulated in the order /o/, /u/ > /a/ > /e/ > /i/ at the word initial position, and /u/ > /i/ > /a/ > /ə/ in the word medial position (in Malayalam, vowel /ə/ does not occur in the initial position nor vowels /e/, /o/ in the medial position), indicating that the vowel /u/ was comparatively more misarticulated at both positions. **Table 2** presents a confusion matrix formulated for short vowels containing the percentage of correct productions and substitution errors. The most commonly seen error



	S /a/	O /a/	S /i/	O /i/	S /u/	O /u/	S /e/	O /e/	S /o/	O /o/	S /ə/	O /ə/
Initial	9.18	4.08	4.29	1.43	10.20	4.08	9.52		14.29			
Medial	8.36	3.23	8.79	6.59	9.52	9.52					0.60	0.60

Short vowels & position

Figure 1. Articulatory errors for short vowels at word initial and medial positions

Table 2. Confusion matrix for short vowels

Target vowel		Initial					Medial			
		/a/	/i/	/u/	/e/	/o/	/a/	/i/	/u/	/ə/
Vowel produced (percent)	/a/	86.73	–	–	–	–	88.41	–	–	–
	/i/	1.02	94.29	–	4.76	–	0.54	84.62	–	0.60
	/u/	–	–	85.71	–	–	–	–	80.95	–
	/e/	1.53	–	–	90.48	14.29	0.54	–	–	–
	/o/	0.51	–	–	–	85.71	–	–	–	–
	/ə/	1.02	1.43	–	–	–	4.04	2.20	4.76	98.81
	/a:/	5.10	–	–	–	–	2.43	–	–	–
	/i:/	–	2.86	–	–	–	0.54	6.59	–	–
	/u:/	–	–	10.20	–	–	–	–	4.76	–
	/e:/	–	–	–	4.76	–	–	–	–	–
	/o:/	–	–	–	–	–	0.27	–	–	–

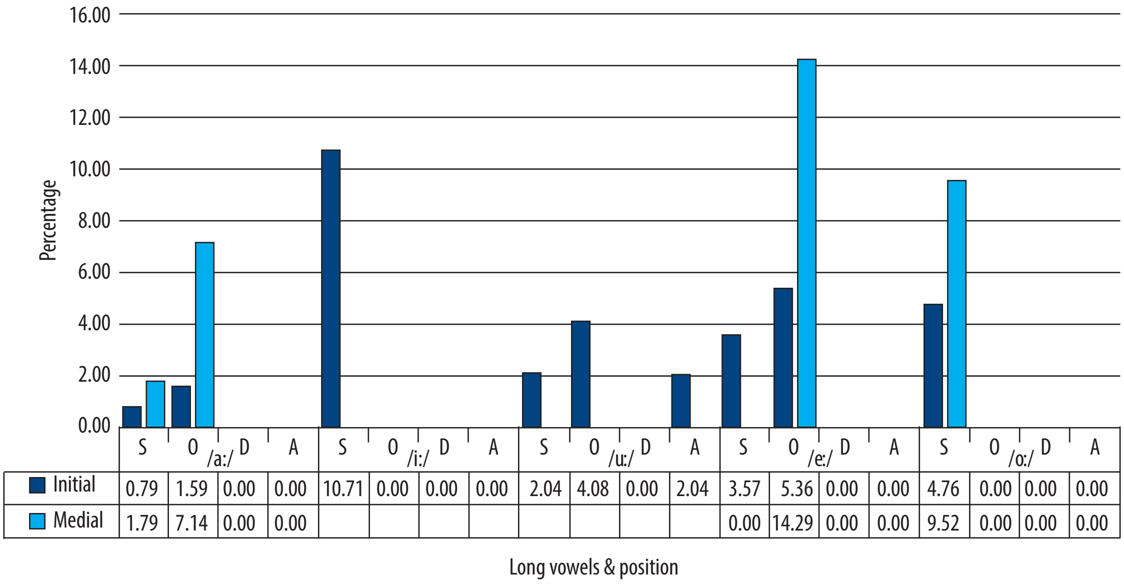
was substitution of mid-central vowel /ə/ at the medial position for all other short vowels.

Long vowel errors

The long vowels were mostly produced correctly by children with HI. Of the misarticulated productions, substitution errors and omission errors were more prevalent than other errors. **Figure 2** shows the percentage of articulatory errors for long vowels at the initial and medial positions. The order of frequently misarticulated vowels was /a:/ < /o:/ < /u:/ < /e:/ < /i:/ at the initial position and /a:/ < /o:/ < /e:/ at the medial position. That is, it was observed that the long vowel /e:/ was comparatively most affected in both positions.

Consonant errors

The consonants were analysed for both SODA and PMV errors. The PMV analysis is exclusively carried out for substitution of consonants to identify the specific error types.



	/a:/ S	/a:/ O	/a:/ D	/a:/ A	/i:/ S	/i:/ O	/i:/ D	/i:/ A	/u:/ S	/u:/ O	/u:/ D	/u:/ A	/e:/ S	/e:/ O	/e:/ D	/e:/ A	/o:/ S	/o:/ O	/o:/ D	/o:/ A
Initial	0.79	1.59	0.00	0.00	10.71	0.00	0.00	0.00	2.04	4.08	0.00	2.04	3.57	5.36	0.00	0.00	4.76	0.00	0.00	0.00
Medial	1.79	7.14	0.00	0.00									0.00	14.29	0.00	0.00	9.52	0.00	0.00	0.00

Figure 2. Articulatory errors for long vowels at word initial and medial positions

Type of error (SODA analysis)

The percentage of SODA errors was calculated for each consonant, and the findings are presented in **Figure 3**. Velar stop /k/ had more errors of substitution in the initial and medial positions. Its voiced counterpart /g/ had prominent substitution errors in the medial position, and omissions in the initial position. The retroflex stop consonant /ʈ/ and its voiced cognate /ɖ/ showed substitution more errors in the initial position compared to the medial position, and omissions were more often in the medial position for both. Distortion errors were observed only in a small percentage, for /k/ at the initial and /ɖ/ in the medial position. Retroflex sounds occupy a prominent place of articulation in most Indian languages and in spoken Malayalam its frequency of occurrence is 4.44% [35]. Palatal affricate /ʧ/ and its voiced counterpart /ʤ/ had more prominent substitution errors in the medial position compared to the initial position. Errors of omission were observed to occur more in the medial position. Further, distortion errors were noted in the initial position for both /ʧ/ and /ʤ/.

The alveolar fricative /s/ showed errors of substitution equally in both initial and medial positions. Palatal fricative /ʃ/ and retroflex fricative /ʂ/ exhibited predominantly substitution errors (medial position for /ʃ/ and initial position for /ʂ/). Errors of distortion were observed in the initial position for /s/ and medial position for /ʂ/.

For alveolar flap /ɾ/, more errors of distortion occurred, followed by substitution errors in the medial position and omission errors in the initial position. Retroflex trill /r/ presented more errors of omission and substitution in the medial position. Additionally, distortion errors were prominent in the initial position. The phonotactics of Malayalam permit nasal retroflex /ɳ/ and lateral retroflex /ɭ/ only in the medial and final positions of words. For these retroflex sounds, substitution errors were observed in higher percentages than omission errors in the medial position. Additionally, it was also noted that the front sound dental /t/ was often substituted for /k/, /ʧ /, /ʤ/, /s/, and /ʃ/ at both word initial and medial positions.

Type of error (PMV analysis)

The PMV analysis was performed for the substitution errors and classified, based on occurrence, as P (place error); M (manner error); V (voicing error); PM (place and manner error); PV (place and voicing error); and PMV (place, manner, and voicing error). **Table 3** summarises the percentages of PMV errors for each class of consonants.

Velar stops (/k/ and /g/)

Velar stop /k/ demonstrated significantly more place errors at the initial and medial positions (100%). At the initial position, the voiced velar stop /g/ showed more place errors while at the medial position devoicing errors (/k/ for /g/) were observed. For both velar cognates, the substitution with dental stop /t/ was the most common place error.

Palatal affricates (/ʧ/ and /ʤ/)

At the initial and medial position, /ʧ/ was shown to have more PM errors (initial, 100%; medial, 83.3%). Its voiced counterpart /ʤ/ had both PM and PMV errors equally in both positions (50%). For both cognates of palatal affricates, /ʧ/ and /ʤ/, substitutions with dentals were the most common place of articulation error and stops for affricates was the most common manner error.

Retroflex stops (/ʈ/, /ɖ/)

The unvoiced retroflex /ʈ/ showed mainly place errors at both initial and medial positions (100%), while its voiced cognate /ɖ/ showed more PV errors in the initial position (100%). Velar for retroflex was the most common place

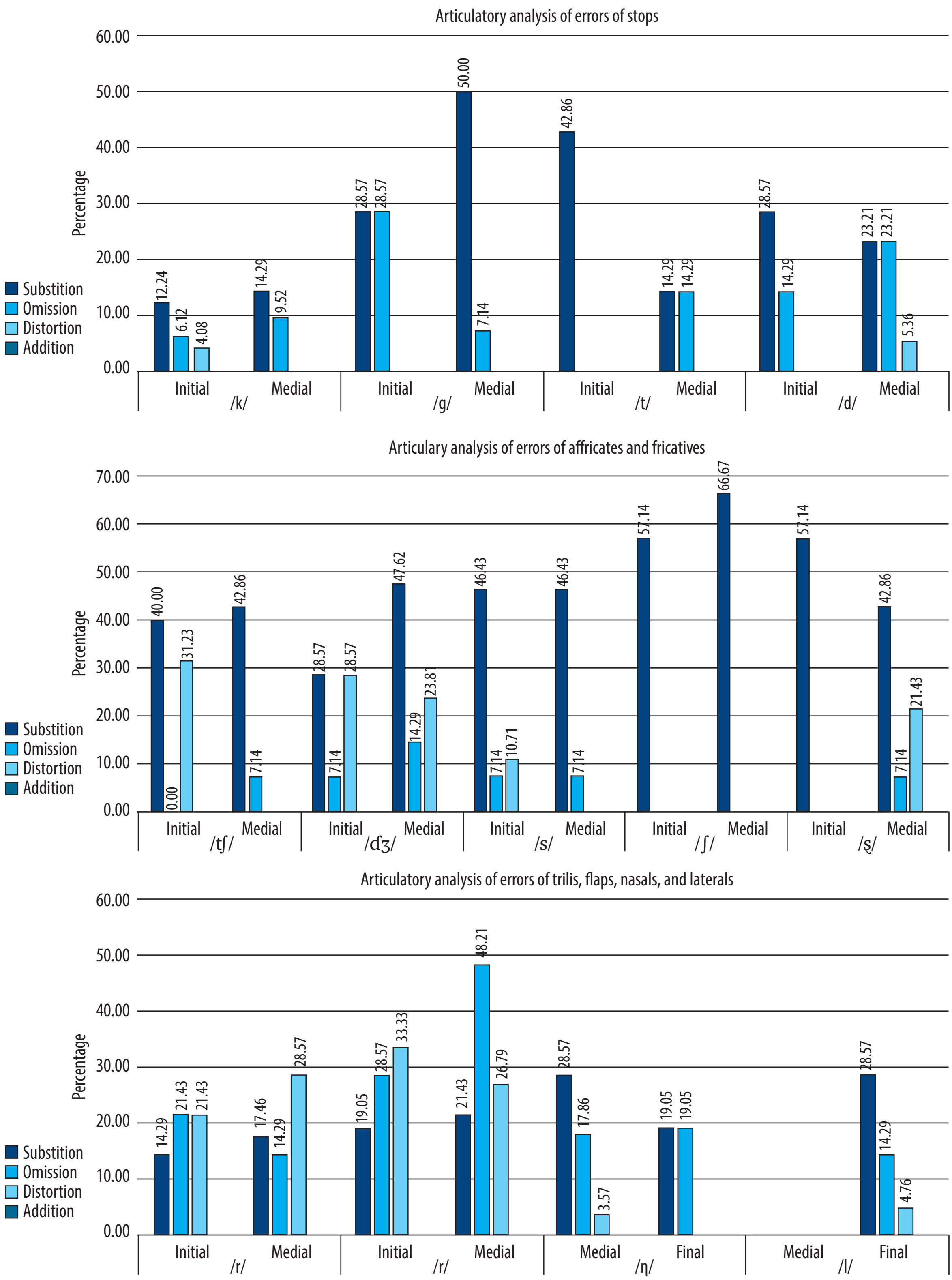


Figure 3. Articulatory errors for different classes of consonants at word initial, medial, and final positions

Table 3. Place–manner–voicing analysis of consonant productions

Target	PMV analysis (%)												
	P			M		V		PM		PV		PMV	
Position	I	Me	F	I	Me	I	Me	I	Me	I	Me	I	Me
/k/	100	100	–	–	–	–	–	–	–	–	–	–	–
/g/	100	14.3	–	–	–	–	71.4	–	14.3	–	–	–	–
/ʧ/	–	–	–	–	16.7	–	–	100	83.3	–	–	–	–
/ʤ/	–	–	–	–	–	–	–	50	50	–	–	50	50
/ʈ/	100	100	–	–	–	–	–	–	–	–	–	–	–
/ɖ/	–	38.5	–	–	–	–	15.4	–	7.7	100	38.5	–	–
/s/	7.7	7.7	–	–	–	–	–	92.3	92.3	–	–	–	–
/ʃ/	–	21.4	–	50	28.6	–	–	50	50	–	–	–	–
/ʂ/	25	16.7	–	–	50	–	–	75	33.3	–	–	–	–
/ɾ/	–	–	–	–	45.5	–	–	50	36.4	–	–	50	18.2
/r/	–	50	–	–	–	–	–	75	41.7	–	–	25	8.3
/ɳ/	–	100	100	–	–	–	–	–	–	–	–	–	–
/ɭ/	–	100	–	–	–	–	–	–	–	–	–	–	–

P, place; M, manner; V, voicing; PM, place and manner; PV, place and voicing; PMV, place, manner, and voicing; I, initial; Me, medial; F, final

error type in initial positions for /ʈ/ and /ɖ/. A manner error was observed, although in lesser percentage, for /ɖ/ and anterior dental nasal /n/ (7.7%), mostly at the medial position.

Alveolar fricative (/s/)

PM errors were observed more for /s/ at the initial and medial positions (92.3%). Dental for alveolar was the most common type of place error, while stops for fricatives was the predominant manner error in both positions.

Palatal fricative (/ʃ/)

The palatal fricative /ʃ/ showed more PM errors (50%) at the initial and medial positions. Affricate for fricative was the most common manner error at the initial position, while dental for palatal was the most common place error.

Retroflex fricative (/ʂ/)

PM errors were more common at the initial position for /ʂ/ (75%). Dental stops were the common type of substitution at the initial position and palatal affricate at the medial position.

Alveolar flap (/ɾ/)

Both PM and PMV type of errors were observed at the initial position (50%) for /ɾ/. The most common place error was dental for alveolar at the initial position and labiodental for alveolar at the medial position. Glide for flap and stop for flap were noted at the initial and medial positions respectively.

Retroflex trill (/r/)

Mostly PM errors were observed for /r/ at the initial position (75%) and place errors at the medial position (50%). At the initial position, dental for retroflex was the main place error whereas stop for trill was the major manner error. The most common place error was alveolar for retroflex, and the most common manner error was nasal for trill at the medial position.

Retroflex nasal (/ɳ/)

Phonotactics of Malayalam allow this phoneme to manifest only in word medial and in word final positions of commonly used English loan words. Predominant P errors were seen in both medial and final positions (100%). Alveolar for retroflex was the most commonly occurring place error.

Retroflex lateral (/ɭ/)

According to the phonotactics of Malayalam, this phoneme presents in the word medial and final positions of commonly used English loan words. P errors were only noted for /ɭ/ at the medial position, with alveolar for retroflex type of substitution.

Overall, it can be concluded that in the speech of HI children, dental place of articulation was mostly substituted for alveolar, retroflex, palatal, and velar places of articulation. Considering the manner of articulation, stops were substituted predominantly for affricates, fricatives, trills, and laterals. Devoicing errors were greatly observed for stops (/g/, /ɖ/) and affricates (/ʤ/). Errors of place and manner, and errors of place of articulation only, dominated over other errors in both word initial and word medial positions.

Discussion

In order for HI children to have the opportunity to gain access to sounds and spoken language, it is desirable that they are continually aided with optimally fitted HAs [50]. The prime objective of this study was to identify the frequently misarticulated vowels and consonants in the speech of Malayalam speaking HI children who used digital HAs. The frequency of misarticulation of short vowels by the participants of the study was /u/ > /o/ > /a/ > /i/ > /e/ > /ə/ and for the long vowels /iː/ > /eː/ > /uː/ > /oː/ > /aː/. This error order varies from the findings for Malayalam speaking children who use CIs [7,12]. Although with a CI the least accuracy was reported for the vowel /o/, two other vowels, /e/ and /u/, were also articulated with effort. Likewise, the findings of the current study report are similar, except for the short vowel /e/ which was produced with relative ease by the participants. The similarities in the findings across these studies could be due to the same stimuli as well as to the similar language, culture, and development of the children. However, one reason for differences in the findings, especially for the ease of production of the short vowel /e/, could be due to a variation in the perception of speech sounds from CIs and HAs, resulting in differences in how speech is produced as well.

This study also found differences in frequently occurring short and long vowels. This was most obvious across the short and long pairs /i/ and /iː/ as well as /e/ and /eː/. Either the short vowel or the long vowel was easier to produce compared to its temporal cognate. This can be attributed to poorer perception and production of temporal cues by children with a HI [8] which leads to tense/lax confusions [13,14]. The current findings agree with the existing literature that consonants are more misarticulated than vowels, since vowels do not require as much precision in their articulatory positions compared to consonants [9,12]. Similarly, this study also endorses the findings of earlier studies which have reported neutralization to a central vowel and substitution among nearby vowels in the vowel quadrilateral [5,12–14]. The current findings are also similar to those of Joy [12], another Malayalam study which reported substitution to be the most frequent vowel error among both long and short vowels in children with a CI. Findings on frequently misarticulated vowels have been less explored in the literature than have consonants. In this way, the current study adds to the literature on the most frequently misarticulated vowel sounds of Malayalam speaking HI children who use digital HAs.

Frequently misarticulated consonants were in the order /r/ > /ʤ/ > /ʂ/ > /ʧ/ > /ʃ/ > /ɾ/ > /g/ > /s/ >/ɖ/ > /ɭ/ > /ɳ/ > /ʈ/ > /k/. Generally, trills, affricates, and fricatives are misarticulated more frequently than other classes of speech sounds [12,18,19]. The reason could be the complex articulation required for the retroflex trill /r/, or the perceptual difficulties HA users have in hearing it. Similarly, errors in producing the speech sound /ʤ/ and /ʧ/ can be attributed to the inherent complexity of these sounds or to the temporal characteristics of affricates which have been reported in acoustic studies [41]. Note that in South Asian languages affricates are phonetically inconsistent and wavering compared to other consonants [51].

The frequent error productions of the fricatives /ʂ/ and /ʃ/ might be ascribed to the perceptual difficulties with fricatives that children with HI have [52]. Inability to hear the highest frequencies deprives HI children of the high-frequency acoustic cues, which in turn leads to difficulties in the production of fricatives. The recent literature suggests perceptual deficits in children with speech sound disorders [53], and this would not be unusual in children with HI.

The literature reports that children with a CI tend to frequently demonstrate distortions, while children with a HA commonly exhibit omission errors [38,54]. At the same time, Joy [12] found substitutions to be frequent among the SODA errors in children using a CI. Comparable results were observed in the present study, with a higher percentage of substitution errors than omission errors in children using HAs. The impact of speech and language therapy prior to recruitment to the current study might have contributed to this finding.

The current findings also report a higher occurrence of errors of place of articulation rather than manner and voicing errors. Dental sounds, due to their enhanced visibility and anterior placement, often replaced other places of articulation [17,22]. In order to explain such a finding, Joy [12] cited Jakobson's (1941) structuralist model of phonological acquisition in which children differentiate vowels before consonants. Consonantal contrast (nasal/oral) and place variations emerge later. Errors of substitution are often described in the word initial position [23]. However, the current findings reveal prominent substitution errors in both word initial and medial positions. This variation in findings could be due to the small number of participants involved in the current study. Regarding the manner of articulation errors, substitution using stops (/t/, /d/) were more common and is comparable to the results reported by Baudonck et al. [54]. This can be attributed to the early acquisition of stop consonants [19] and also to their inherent ease of production due to anterior placement.

Findings of the current study also revealed a higher number of devoicing errors for various classes of speech sounds (stops and affricates), which is congruent with the existing literature [12,20]. In order to differentiate voiced and unvoiced cognates, the contrasts are small and the difficulty in mastering the fine motor control of voicing makes it a late acquired feature in speech acquisition [55].

Conclusions

The current study has carried out a descriptive articulatory error analysis of 7 children with congenital hearing impairment who used suitable digital hearing aids. Speech samples from these participants were acquired in tele-mode and offline transcription were then done. Vowel and consonant errors in the speech of these participants were determined and contrasted. Various error patterns of vowels and consonants were observed. Specifically, the vowels /u/ and /i:/ were found to be the most frequently misarticulated vowels. Similarly, the most frequently misarticulated consonants were trills (/r/), affricates (/ʤ/, /ʧ/), and fricatives (/ʂ/, /ʃ/). Among the various types of SODA errors, substitution errors were the most predominant for both vowels and consonants. PMV analysis was suggestive of more frequent place–manner and place errors.

In order to facilitate the speedy acquisition of speech sounds and improve the speech intelligibility of children with HI, articulation therapy needs to target the commonly misarticulated phonemes. The current study highlighted frequently occurring vowel and consonant errors in Malayalam speaking HI children aided with digital HAs. As this was an exploratory study no formal sample size estimations were carried out, and future studies could replicate our methodology on a larger and statistically estimated sample. If such studies were conducted in other Indian languages, they could provide guidelines for speech language pathologists in planning interventions for HI children so as to enhance their speech intelligibility and improve their quality of life.

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