

Articulatory Error Analysis in Kannada Speaking Children with Hearing Impairment: An Exploratory Study

N. Sreedevi^{1*}, Anusmitha Mathew², Reshma O.²

Abstract

Speech sound errors are common in children with hearing impairment even after extensive speech therapy. Studies investigating the articulatory characteristics of children using hearing aids are relatively less reported in Indian languages. This study examined the nature of speech sound errors in Kannada speaking children with hearing impairment in comparison with age matched normal hearing peers. A detailed articulatory analysis was carried out from recorded speech samples. Research comparing articulatory characteristics between children with hearing impairment and those with normal hearing reveals significant differences. Among children with hearing impairment, certain vowels such as /i/ and diphthongs like /i:/ and /e:/ are frequently misarticulated. Additionally, consonants including fricatives (/s/, /ʃ/), lateral (/l/), and affricate (/dʒ/) are commonly mispronounced. The distribution of speech sound errors varies across word-initial and medial positions, with substitutions being the most prevalent error type observed. Furthermore, place errors tend to occur more frequently than manner and voicing errors. These findings underscore the unique articulatory challenges faced by children with hearing impairment, highlighting the importance of tailored interventions in speech therapy programs. Such error analysis of speech sounds, augments better understanding of speech of children with hearing impairment leading to effective intervention and better speech intelligibility.

Keywords: Hearing impairment, articulatory errors, digital hearing aids, consonant errors, vowel errors

INTRODUCTION

A major consequence of hearing impairment (HI) is reduced repertoire of sound segments, mainly consonants leading to poor communication skills. Speech of children with hearing impairment (CwHI) is characterized by numerous segmental errors, including vowel neutralisation, omission of word-final consonants, confusion of voiced voiceless cognates and manner and place errors [1]. Despite being aided early in life, CwHI seldom correct their articulation to the same extent as their normal hearing peers due to reduced efficient hearing.

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Speech sound acquisition and accuracy serve as major yardstick in measuring speech development and speech intelligibility. Studies in typically developing children in the Indian languages of Kannada [2], Malayalam [3], Hindi [4], and Tamil [5], report that all consonants including clusters attain 90% mastery by 5.6 years of age or earlier. However, when considering consonant production in children who are prelingually hard of hearing, reduced inventories are described compared to CwNH [6]. Children with hearing impairment are less accurate in consonant production than CwNH; even though, they follow a typical speech sound

developmental pattern [7]. Literature on the acquisition of consonants in CwHI suggest a predominance of early-appearing stops, glides, and nasals and mid-level stops [8].

An in-depth analysis of the articulatory errors of CwHI is necessary to establish systematic guidelines for speech sound correction. Errors on consonant production are phonetic errors at the segmental level and can be classified based on 'SODA' taxonomy (Substitutions, Omissions, Distortions and Additions) [9]. Further, substitution error patterns can be classified in terms of place, manner, and voicing (PMV) features of each consonant.

Further phonetic contexts such as position in a word or syllable, vowel context, etc. are key environments that facilitate the acquisition and production of speech sounds according to the phonotactic rules of the language. In the Indian context, the effect of phoneme positions on acquisition of speech sounds have been discussed in typically developing children [2–3, 10–12]. The acquisition of affricates and fricatives in Malayalam speaking CWHI is similar to typically developing children with affricates being facilitated in medial and fricatives in the initial position [13]. In sum, these studies conclude their findings with key positions for different phonemes and highlight that they are language dependent.

Majority of studies profiling articulatory errors in CwHI have been carried out among children using cochlear implants (CI) [14–16] and few studies have compared articulatory characteristics of CI with conventional hearing aids (HAs) users [17, 18]. Children using HAs tend to demonstrate significantly more phonetic and phonological disorders than those using CI [19]. Articulatory error analysis of vowels and consonants among Malayalam speaking children with CI [14] and HA [20] have revealed that substitution errors were the major consonant error type, and place errors were more frequent than manner errors. Devoicing errors were also predominant. Differences were found across classes of sounds relating to the position within a word.

In India, majority of CwHI are fitted with HAs only by 3 years of age due to late identification of hearing loss. This leads to persistent articulatory errors even at the age of 5 to 7 years. Option of CI is considered when HA is found to be of very limited use. Despite a higher number of HA users, there is a dearth of Indian literature investigating the frequently misarticulated sounds and error types in children fitted with digital HA. Existing literature focuses primarily on analogue HA users. Analogue processing provides lesser precision and reliability, and more additive noise, when compared to digital processing. Thus, there is a need to investigate the articulatory characteristics of digital HA users, which are in par with CI in terms of higher quality of signal processing [21]. Hence the present study involved a standard group comparison aimed to investigate the frequently misarticulated speech sounds in Kannada speaking CwHI using digital HA and compare with age matched peers.

MATERIALS AND METHODS

Participants

This study involved two groups of participants. Group I included nine Kannada speaking children in the age range of 5 to 7 years diagnosed as spoken-language disorder secondary to hearing impairment (CwHI), and have attended speech-language therapy services for at least 2 years before participation in the study. CwHI were fitted with digital HA and their aided audiometric thresholds were within the speech spectrum. Group II consisted of nine age and gender matched Kannada speaking normal hearing children (CwNH). CwNH had age adequate language skills with no history of communication impairments or any associated sensory, cognitive, or motor disorders. Both groups of participants were assessed using Assessment Checklist for Speech and Language Skills (ACSL) [22] and Developmental Screening Test (DST) [23].

Participants were recruited using convenience sampling. Ethical clearance was obtained from the Ethical Board of the Institution under study. A written consent was obtained from parents of all

participants.

Procedure

The articulatory skills of the participants were assessed using the Kannada Diagnostic Picture Articulation Test (KDPAT) [2]. The assessment was carried out in tele-mode through Zoom or Google meet platforms with stable internet and appropriate bandwidth was ensured. If target word was not spontaneously elicited, repetition task was employed to elicit a verbal response. The total assessment time was approximately 1½ h for each participant and was completed in two to three sittings. The recorded data was transcribed using IPA (International Phonetic Alphabet) [24].

Data Analysis

The recorded data of single word responses was analysed by a trained Speech-Language Pathologist (SLP). Each target phoneme was assessed in all stimulus words/positions wherever it occurred in the list of words in KDPAT to get a comprehensive impression of the child's production in different linguistic contexts. The following phonemes were analysed: Five short vowels (/a/, /i/, /u/, /e/ and /o/); five long vowels (/a:/, /i:/, /u:/, /e:/ and /o:/) (a total of 19 contexts for word-initial, 148 for word-medial and 107 for word-final positions) and 11 consonants (/k/, /g/- unvoiced and voiced velar stops, /tʃ/, /dʒ/- unvoiced and voiced palatal affricates, /t̪/, /d̪/- unvoiced and voiced retroflex stops, /s/- alveolar fricative, /ʃ/- palatal fricative, /r/- retroflex trill, /ŋ/- retroflex nasal and /l/- retroflex lateral). The consonants were tested in 44 contexts for word-initial and 88 for word-medial positions.

Error productions were scored '0' and correct productions were scored '1'. Number of error productions were calculated for all vowels and consonants produced by each participant and converted to percentages. To determine the frequency of type of errors, a qualitative analysis (SODA and PMV) was carried out.

Qualitative Analysis of Vowels

Vowels were analysed for articulatory deviations as listed:

1. Substitution of one vowel for another e.g., /gine/ for /gini/.
2. Omission of one vowel/syllable e.g., /i|j:mane/ for /i|j:gemane/.
3. Target vowel distortion produced as a non-Kannada sound.
4. Addition of a sound to the target vowel e.g., /ko:le/ for /o:le/.

Frequency and percentage of error was calculated and an in-depth analysis of vowel substitutions was carried out.

Qualitative Analysis of Consonants

Frequency and percentage of SODA errors was calculated for all consonants tested. Further, PMV analysis of substitution errors was carried out in initial and medial word positions and percentages were computed.

RESULTS

Frequently Misarticulated Speech Sounds

The frequently misarticulated short vowels in Kannada of CwHI in ascending order were /i/>/o/>/a/>/e/>/u/. Similarly, frequently misarticulated long vowels were /e:/=>/i:/>/a:/>/o:/>/u:/. No vowel errors were seen in CwNH.

Consonants /s/, /ʃ/, /k/, /g/, /r/, /l/ and /dʒ/ were frequently misarticulated by all CwHI. The order of most misarticulated speech sounds was found to be /s/>/ʃ/>/l/>/dʒ/>/d/>/r/>/g/>/tʃ/>/t̪/>/k/>/ŋ/ i.e., the fricatives were the most affected consonants and retroflex nasal /ŋ/ was the least affected consonant. Consonant errors were rarely noticed in age matched CwNH. The mean error percentage of vowels and consonants for CwHI is tabulated in Table 1.

Vowel Errors

Articulatory analysis of CwHI for vowels revealed higher occurrence of substitution and omission errors mostly in the medial position followed by initial and final positions (Figures 1 and 2). There were no distortion and addition errors (except for long vowel /o:/ in the initial position by one of the participants). At the word-initial position, short vowels were misarticulated in ascending order of /i/=e/>/u/=o/>/a/, in the medial position, /o/>/i/>/e/>/u/>/a/ and in the final position /i/>/e/>/u/>/a/. Substitution of neutral mid-central vowel /ə/ for other short vowels was the most common error seen. Long vowels were most often produced correctly and the order of frequently misarticulated long vowels were /i:/>/o:/>/a:/=/u:/=/e:/ at the word-initial and /e:/>/i:/>/a:/>/o:/>/u:/ at the medial positions (long vowels did not occur at word-final positions except one context each for vowels u: and o:). Substitutions of vowel /a/ for other long vowels was the most common error seen.

Table 1. Mean Percentage of Error for Vowels and Consonants for CWHI.

Short Vowels	% Mean Error (±SD)	Long vowels	% Mean Error (±SD)	Consonants	% Mean Error (±SD)
/a/	9.11 (12.45)	/a:/	8.8 (8.7)	/k/	56.30 (27.41)
/i/	11.9 (15.34)	/i:/	11.11 (16.67)	/g/	66.67 (30.30)
/u/	6.78 (8.6)	/u:/	2.22 (4.4)	/tʃ/	65.43 (28.02)
/e/	7.28 (8.35)	/e:/	11.11 (14.53)	/dʒ/	82.22 (27.28)
/o/	11.11 (16.67)	/o:/	5.13 (5.44)	/t/	59.72 (34.95)
				/d/	81.82 (32.78)
				/s/	85.62 (18.63)
				/ʃ/	84.72 (16.27)
				/r/	79.86 (19.02)
				/ŋ/	53.33 (41.23)
				/l/	82.54 (27.46)

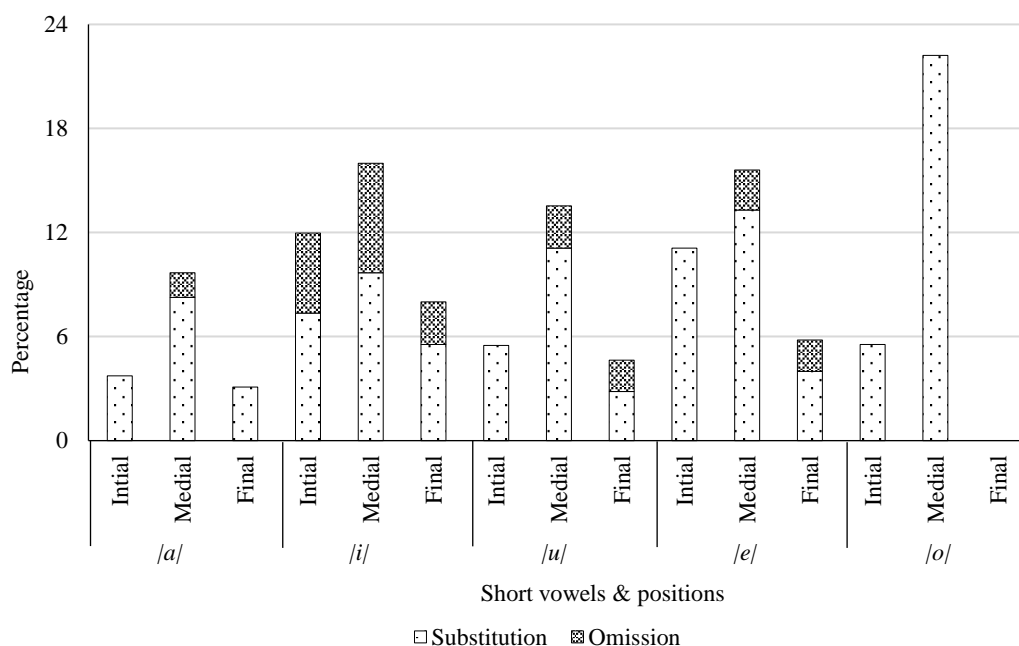


Figure 1. Articulatory Error Percentage of Short Vowels at Word-Initial, Medial, and Final Positions.

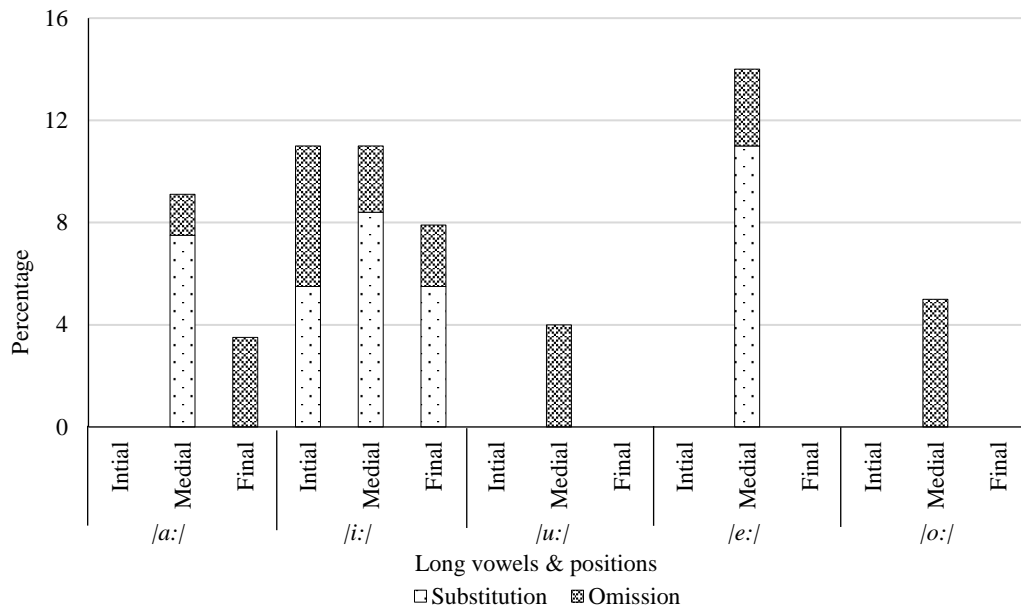


Figure 2. Articulatory Error Percentage of Long Vowels at Word-Initial, Medial, and Final Positions.

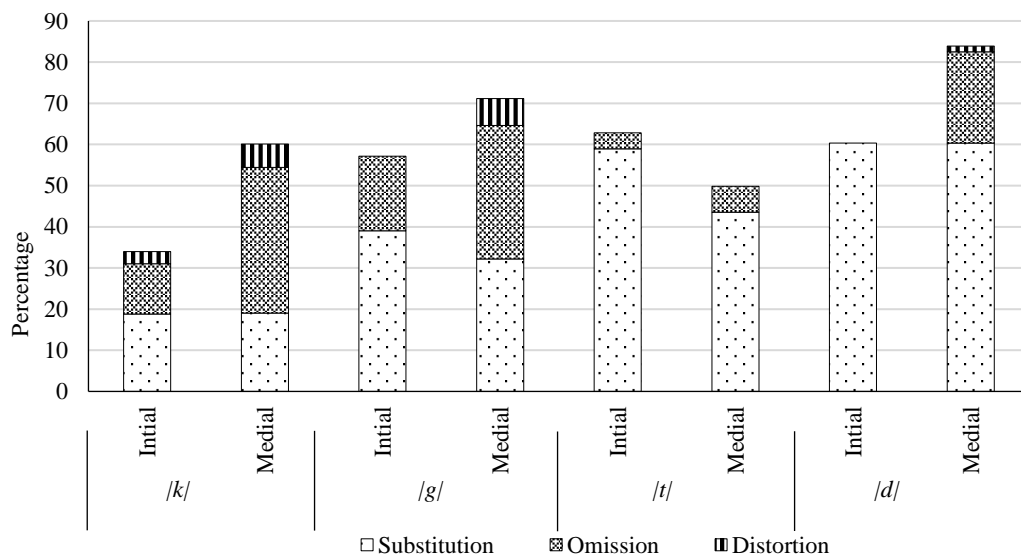


Figure 3. Articulatory Error Percentage of Stops at Word-Initial and Medial Positions.

Consonant Errors

As the phonotactics of Kannada permits consonants in initial and medial positions only, consonants were analysed in these two positions. Percentages of articulatory errors were calculated for all consonants and the findings are represented in Figures 3–6. Addition errors were seldom seen in any of the participants.

Consonant Errors in CwHI

Velar /k/ depicted more omission errors in word-medial than initial position and substitution errors were almost equally present in both initial and medial positions. Velar cognate /g/ showed more errors of substitution in word-initial position and omissions in word-medial position. Affricates /tʃ/ and /dʒ/ showed significant substitution errors in the medial position compared to initial position. Omission errors were observed in both positions for /tʃ/, though /dʒ/ had more omissions in medial position. Further, a higher number of distortions were noted in the initial position for /dʒ/ and in medial position for /tʃ/.

Both fricative consonants /s/ and /ʃ/ showed more substitution errors in word-initial and word-medial positions. More omissions were seen for trill /r/ than substitutions in both positions.

The retroflex stop /ɭ/ showed prominent substitution errors in the initial compared to the medial position, and the omissions were relatively fewer. Similar findings were observed for its voiced cognate /dɭ/. Substitutions were higher than omissions for retroflex sounds (/ɭ/, /dɭ/, /ŋɭ/, /lɭ/). Also, it was noticed that /k/, /tʃ/, /t/, and /s/ were substituted with an anterior sound, (often dental stop /t/) in both positions. Fronting was also observed at the medial position for /dʒ/ and /ʃ/.

Consonant Errors in CwNH

Children with normal hearing did not exhibit errors on consonants /k/, /g/, /tʃ/, /t/, and /s/. The substitution errors observed in few participants include voiced affricate /dʒ/ by /tʃ/ and dental /d/ in word-initial position and no errors were observed in word-medial position. Consonants /dɭ/, /ʃ/ and /r/ were substituted negligibly with other consonants in both initial and medial positions. Retroflex nasal /ŋɭ/ and lateral /l/ showed fronting errors occasionally.

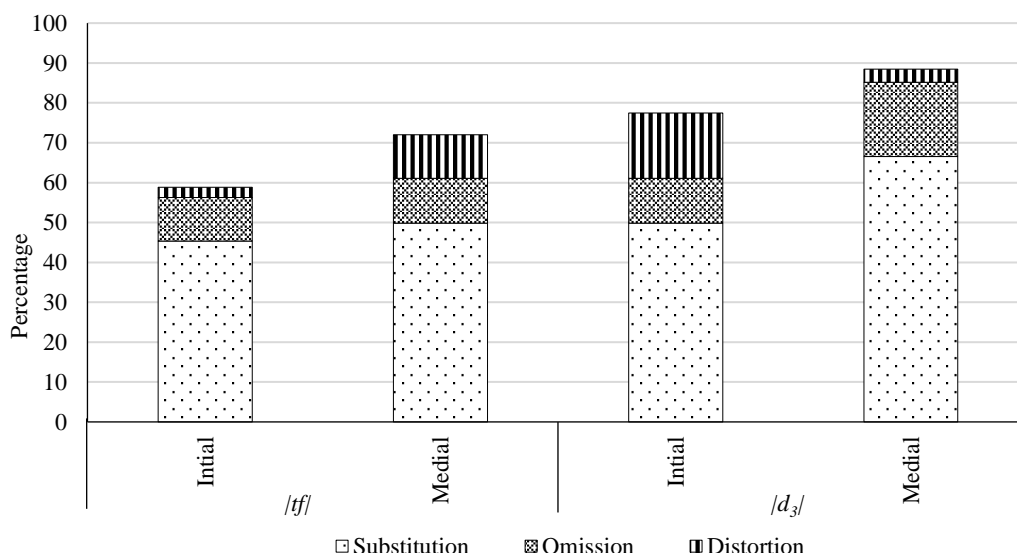


Figure 4. Articulatory Error Percentage of Affricates at Word-Initial and Medial Positions.

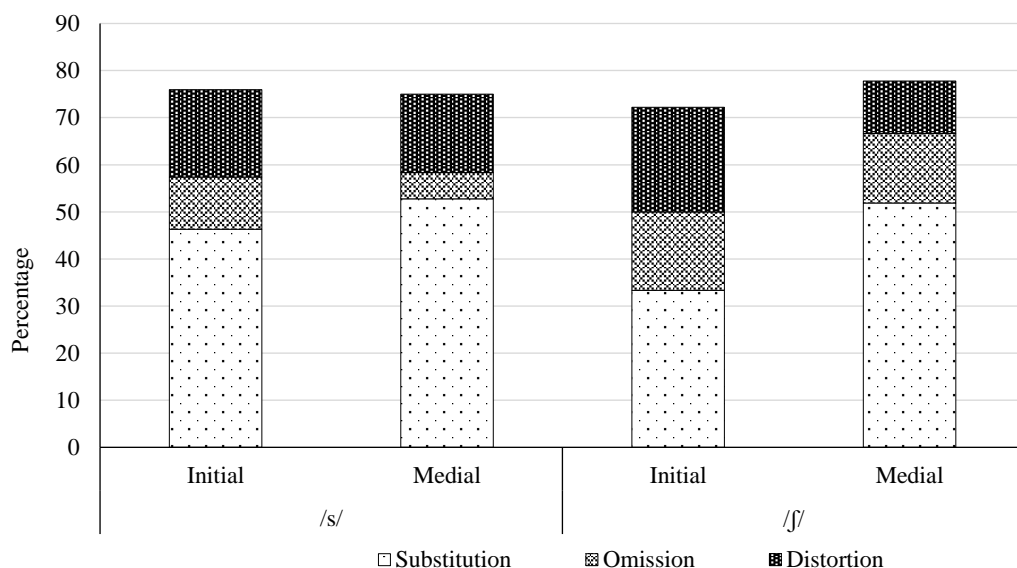


Figure 5. Articulatory Error Percentage of Fricatives at Word-Initial and Medial Positions.

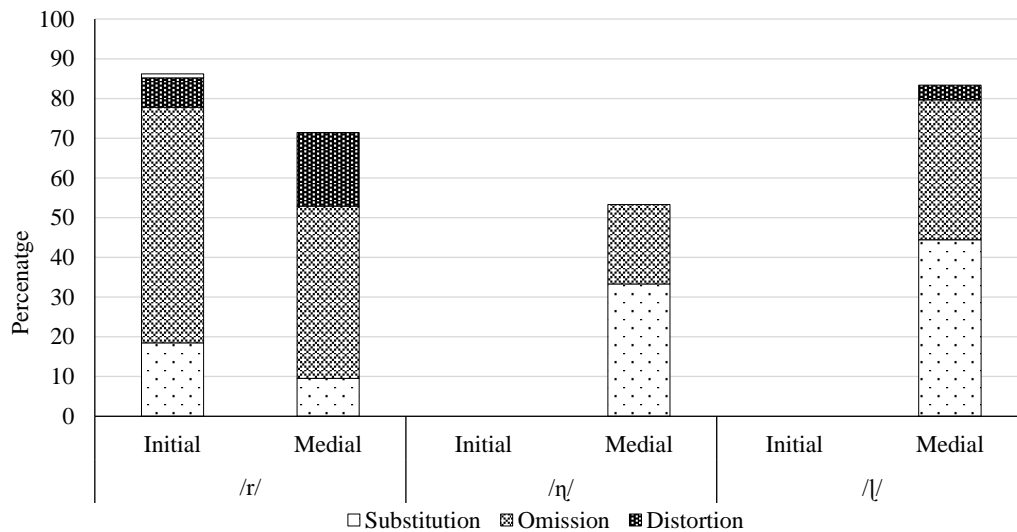


Figure 6. Articulatory Error Percentage of Trill, Nasal and Lateral at Word-Initial and Medial Positions.

Table 2. Place Manner Voicing (PMV) Percentage Error Analysis of Consonant Productions.

		PMV error analysis (%)												
		P		M		V		PM		PV		PMV		
	Position	I	M	I	M	I	M	I	M	I	M	I	M	
Target consonants	/k/	92.6	95.2	-	-	-	-	7.4	4.8	-	-	-	-	
	/g/	28.6	45.7	-	-	66.7	31.4	-	8.6	4.8	11.4	-	2.9	
	/ŋ/	-	-	-	11.1	-	-	100	88.9	-	-	-	-	-
	/dʒ/	-	-	-	-	44.4	16.7	-	33.3	-	-	55.5	50	
	/t/	100	100	-	-	-	-	-	-	-	-	-	-	
	/d/	76.9	69.4	-	2	23.1	16.3	-	8.2	-	2	-	2	
	/r/	-	-	-	-	-	-	60	66.7	-	-	40	33.3	
	/n/	-	73.3	-	-	-	-	-	20	-	-	-	6.7	
	/l/	-	83.3	-	-	-	-	-	12.5	-	-	-	4.2	
	/s/	4	5.3	-	-	-	-	96	84.2	-	-	-	10.5	
	/j/	16.7	-	50	42.9	-	-	33.3	57.1	-	-	-	-	

Note. P: Place; M: Manner; V: Voicing; PM: Place & Manner; PV: Place & Voicing; PMV: Place, Manner & Voicing; I: Initial; M: Medial

Percentage of highest error productions are in bold

Type of Substitution Error (PMV Analysis)

Further PMV analysis was carried out for the substitution errors seen in CwHI. The percentage of PMV errors in CwHI are summarized for each class of consonants in Table 2.

Stops

In CwHI, substitution errors were mainly place errors for /k/, /t/ and /d/. Dental stop (/t/) was the most often substituted sound for these velar and retroflex places of articulation at both initial and medial positions, demonstrating more fronting errors. Manner of articulation errors were minimal; palatal glide (/j/) and bilabial nasal (/m/) were substituted for velar stop /k/. Voiced retroflex stop /d/ was substituted by alveolar lateral /l/. Voiced velar stop /g/ was produced as its unvoiced cognate /k/ in the initial position. /t/ for /g/ was the most seen place error type. The manner error although less, was substitution by nasal (/n/) for stop /g/.

For CwNH, no articulatory errors were observed for consonants /k/, /g/ and /t/. For the voiced retroflex /d/, the lone error at the initial position was place error (substitution by dental /t/). In the medial position, devoicing errors were occasionally seen.

Affricates

In CwHI, for palatal affricates /tʃ/ and /dʒ/, dental stop substitutions were the most common place and manner error. /tʃ/ was observed to have more PM errors in initial and medial word positions, whereas its voiced cognate /dʒ/ showed predominantly PMV errors at both positions. In CwNH, /dʒ/ at the initial position had fewer PM and sometimes voicing errors. No errors were observed in the medial position for /dʒ/.

Trills

In CwHI, PM errors were mostly observed for retroflex trill /r/ in both word positions. At initial position, alveolar (/n/) was the commonly noted place error and lateral (/l/) for trill was the key manner error. At the medial position, dental /t/ and alveolar /l/ substitutions for /r/ were alike as place error and stop /t/ substitution for /r/ was the manner error observed. In CwNH, voiced dental stop /d/ for /r/ was negligibly seen as substitution error.

Nasals

Lone nasal error seen was retroflex /ŋ/. In CwHI, /ŋ/ was observed to have more P errors (alveolar /n/ for retroflex /ŋ/). Similar P errors were occasionally observed in CwNH also suggestive of fronting errors.

Laterals

According to phonotactics of Kannada, lateral retroflex /ɭ/ presents only in the word-medial position. In CwHI, more of P errors was noted for /ɭ/. The most common place error was the front sound alveolar /l/ and manner error was glide /j/, however in insignificant percentage. Similar anterior P errors were also observed for /ɭ/ in few of the CwNH.

Fricatives

For CwHI, alveolar fricative /s/ had more of PM errors at the initial and medial word positions, substitution by dental stop /t/. No fricative errors were present in CwNH. In CwHI, palatal fricative /ʃ/ showed more M errors at the initial position. At the medial position, /ʃ/ was observed to have both P and M errors. For CwNH, alveolar /s/ was occasionally substituted for palatal /ʃ/.

Statistical Comparison Across CwHI and CwNH

The Mann-Whitney U test using SPSS V.26 was used to compare the differences between the two groups (CwHI and CwNH) on the error percentage for both vowels and consonants as the data did not follow normal distribution. Significant differences were found across the groups for all phonemes except for the short vowel /o/ ($Z=-1.844$, $P=0.065$) and long vowel /u:/ ($Z=-1.458$, $P=.145$). Further intra-judge and inter-judge reliability was calculated for 10% of the data of each group by three SLPs based on point-to-point agreement of correct versus incorrect phoneme productions. The overall percentage of agreement for intra-judge reliability for 10% of the data was 90% and inter-judge reliability was 87%.

DISCUSSION

The primary objective of this study was to document and describe the frequently misarticulated vowels and consonants in the speech of Kannada speaking CwHI using digital HA and several salient observations were made. One of the findings of the present study was that vowels /i/ and /e:/ and /i:/ were the most affected vowels in children with HI. Earlier perceptual investigations in individuals with hearing impairment support the finding that back vowels were produced correctly than front vowels, and low vowels than mid or high vowels [1]. Acoustic evidence of vowels suggested that children with HI have lower formant values of F1 and F2. Decrease in the second formant indicates more posterior tongue placement for the front vowels [25, 26] and hence less visibility. However, studies among Malayalam speaking children with CI [14] have reported that /u/ and /o/ are the most frequently misarticulated vowels, whereas children with HA [20] frequently misarticulate on /u/ and /i:/. The

difference could be due to the language and developmental differences of participants. Moreover, the variance in the perception of speech sounds through two different devices (CI & HA) would have resulted in differences in the speech production characteristics as well.

Further, the findings of this study report difference in the production of short and long vowel cognates (/o/ and /o:/ and /i/ and /i:/) in Group 1. This is due to difficulties in the perception and production of temporal cues by CwHI leading to tense lax alterations [1]. Hence correct production of short vowel does not guarantee the correct production of its longer counterpart or vice versa [20].

Studies examining frequently misarticulated vowels are scanty compared to consonants and this study adds on this information in the speech of Kannada speaking CwHI using digital HAs. Findings from this study agree with the existing literature that vowels are more accurately produced than consonants due to the less precise articulatory position and better visibility. Also, substitution was the most common vowel error in accordance with previous studies [14, 20]. Current findings uphold that vowel substitution involves neutralization to a central vowel, or substitution with adjacent vowels in the vowel quadrilateral [1, 14].

Another observation was that, fricatives were found to be most affected consonants in consonance with the existing literature [8, 20]. The perception of fricatives is affected by high-frequency hearing loss owing to difficulties in extracting information from the high-frequency acoustic cues [27].

The lateral retroflex /ɭ/ was reported to have good accuracy in the speech of CI children [14]. However, the current findings reveal that it is frequently misarticulated by children using HAs. Retroflex consonants are difficult to produce and are a prominent place of articulation in most Indian languages. They are physiologically complex sounds produced with the tongue tip or its underside making a constriction in the post-alveolar or palatal area of the mouth [28]. Similarly, incorrect production of affricate /dʒ/ could be due to its complexity and timing evidenced from acoustic studies [15]. Affricates in South Asian languages are phonetically variable compared to other consonants [29].

Comparison of consonant error patterns between children using CI and HA have reported a higher number of distortions among CI group, and a higher number of omissions in the HA group [17, 19]. Conversely, substitution errors were higher than omission errors in HA users in the present study similar to the findings of some of the earlier studies [14, 18, 20]. Earlier age of amplification and the substantial period of intervention attended by the participants would have contributed to this finding.

Another salient finding is that, place errors of articulation were greater than errors of manner and voicing in agreement with earlier Indian studies in Telugu [18] and Malayalam [20]. Dental sounds were the most preferred substitutions for other places of articulation, due to better visibility and anterior placement [7]. Errors of substitution are generally reported in the initial position of words [30], although in the present study, substitution errors were prominent in the medial position.

Considering the manner of articulation errors, stops (dental- /t/, /d/) were frequently substituted for other manner types as reported in literature [17, 20]. Early acquisition of stops [16] and anterior placement would have resulted in this finding.

The current study indicated more devoicing errors for stops and affricates in consonance with earlier studies [31, 14]. Voicing contrasts are insufficient to perceptually differentiate the cognate pairs and the complexity in achieving fine motor control of voicing makes it a late acquired feature in speech acquisition [32].

CwHI and CwNH showed significant differences for percentage of error productions of vowels and consonants. The former has weaker production of consonants while vowels are easier to perceive and produce [7]. On administration of the Mann-Whitney U test, significant differences were not found

across the error productions of long vowel /u:/ and short vowel /o/. This is suggestive of early acquisition and mastery of these rounded more visible vowels by CwHI [33].

It is worth noting that CwNH also exhibited minimal errors on articulatory assessment. These were mainly seen on consonants, perhaps due to individual variabilities [7].

CONCLUSION

This study extensively analysed the frequently occurring vowel and consonant errors in Kannada speaking CwHI, rehabilitated using digital hearing aids. Vowel errors were predominantly substitution errors at the word-medial position. Among the consonant errors, dental place of articulation was most often substituted for alveolar, retroflex, palatal, and velar sounds. Considering manner of articulation, stops were largely substituted for affricates, fricatives, trills and laterals. And voicing errors were more seen for stops and affricates. Place, manner, and voicing errors were observed to be more predominant in the medial than in initial word position for the consonants. Current findings augment Speech-Language Pathologists' (SLPs') knowledge of articulation in children using hearing aids to ensure effective articulation intervention to improve their speech intelligibility.

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