Kurdish Studies
July 2024
Volume: 12, No:5, pp. 514-521
ISSN: 2051-4883 (Print) | ISSN 2051-4891 (Online)
www.KurdishStudies.net

DOI: 10.53555/ks.v12i5.3259

Acoustic Characteristics of Vowel Production in Urdu-Speaking Children with Cochlear Implant

Farwa Haider[1], Naima Farooq[2], Harmain Fatima[3], Rabia Mansoor[4], Nadia Bashir[5], Asia Qadeer[6], Ghulam Saqulain[7*]

[1]MPhil (SLP) & MS Clinical Psychology, Speech Therapist & Psychologist, Department of Rehabilitation Sciences, Riphah International University Islamabad - Pakistan
[2]PhD Scholar, Senior Lecturer, Department of Rehabilitation Sciences, Riphah International University, Islamabad Pakistan
[3]MPhil (SLP) Scholar, Department of Rehabilitation Sciences, Riphah International University, Islamabad - Pakistan
[4]MPhil (SLP), Senior Lecturer, Department of Rehabilitation Sciences, Riphah International University, Islamabad - Pakistan
[5]MS Speech & Language Pathology & MS Psychology, Senior Lecturer, Department of Rehabilitation Sciences, Speech & Language Pathology, Riphah International University, Islamabad - Pakistan
[6]MPhil (HS), HCPC, Consultant SLP, Rehabilitation Sciences, Speech Facilitation and Rehabilitation Clinic
[7*]FCPS (Otorhinolaryngology), HOD, Professor & Deputy Dean, Capital Hospital PGMI, Islamabad - Pakistan

***Corresponding Author:** Ghulam Saqulain
*E-mail: ghulam_saqulain@yahoo.com
Orcid ID: https://orcid.org/0000-0002-6452-9339 Scopus *h* index: 6

Abstract
Objective: To compare characteristics of vowe1 production in normal hearing typical Urdu-speaking children with hearing impaired children using Coch1ear Implants, focusing on time duration and first & second formant frequencies.
Methodo1ogy: This comparative cross-sectional study was conducted at Riphah International University from January to June 2023. Using nonprobability convenience sampling study recruited N=36 children (20 normally hearing & 16 hearing impaired children using cochlear implants with hearing ages of 2 to 5 years. A self-developed questionnaire was used for data collection. Participants were provided with specific sentences consisting of words made with short and 1ong vowels during their sessions. Three different words were made from each vowe1 for three different responses. PRAAT software and SPSS Version 25 were used for data collection.
Resu1ts: When comparing children with cochlear implants to those with normal hearing, there were notable differences in the formant 1 and formant 2 for short and long vowels at three specific points (R1, R2, R3). Additionally, significant variations were identified at R1 ($p = 0.017$), R2 ($p = 0.024$), and no significant variation at R3 ($p = 0.066$). The findings displayed noteworthy differences in F1 for /ʊ/ among children with atypical development compared to those with typical development. These variations were consistent across all three responses (R1, R2, R3). The mean duration for most of the long vowels like /ɔ/ , /o/ ,vowel revealed a significant difference between the two groups in R1, & the mean duration of /ae/ vowel was significantly different in all responses ($p < 0.001$).
Conc1usion: In Urdu-speaking children, discernible differences in formant frequencies 1 and 2, are present between normal-hearing children and those with cochlear implants. The varying sound patterns of the vocal tract illustrate the impact of cochlear implants on vowel pronunciation. These implants significantly influence the spectral aspects of speech, making it critical for a thorough assessment approach to consider both temporal and spectral factors in therapy.

Keywords: Acoustics, Cochlear implants, Formant Frequencies, Hearing Impaired, Time duration,

INTRODUCTION

The most significant and primary channel of the human symbolic communication system recognized as language is speech. Speech makes language audible (1). Voice is characterized by linguistic aspects, specifically, speech sounds like vowels and consonants. It is consequently vital to comprehend both the pattern and characteristics of speech sounds; and to have a basic understanding of voice acoustics to interpret and analyze the speech (1, 2).

Every language has a phonetic blend of consonants and vowels that makes the sound of its word (3). A vowel is a verbal syllable that can be pronounced freely in the vocal tract and it represents an open sound (4). Vowels range in quality, volume, and frequency. They play a key role in phonation such as pitch, intonation, and stress (5). Vowel sounds are uttered with very little airflow blockage, which gives them a distinctive tone. Vowels are perceived as being both louder and longer lasting than consonants because they are more sonorous, or acoustically powerful (6). Three articulatory standards, i.e. front-back, rounded-unrounded, and high-low are used to discriminate between vowels. Vocal tract resonance, utilized to distinguish the vowel sounds known as the formants of the vocal tract is essential for identifying the vowel sounds, Formants, denoted as F1, F2, F3, and so on, are a group of formants associated with vowels and are always higher than the fundamental frequency (f0). The formants of the vowels and the (F0) are not the same. On the other hand, formants depend on the general size and shape of the cavities above the larynx, whilst (F0) is primarily governed by the pace of the vocal cord vibrations in seconds. (7). The length of the vowel is a key factor in segmentation. Duration variability might be phonemic or allophonic (8).

The Urdu language originates from the Indo-European dialect. There are 41 consonants and 11 vowels in Urdu language. One list of Urdu vowels claimed that there are 11 vowel sounds in Urdu, 3 lax (phonetically short) and 8 tensed (phonetically long) (9). The Urdu language had only six temples, the other five being developed from these basic forms. "Biomeric" is a long vowel in Urdu, whereas "mono-moriac" is a short vowel. A mora can be thought of as the temporal equivalent of a single vowel or the consonant of a coda. Bi-moriac, indicating twice longer than the short vowels, is an umbrella term for a long vowel or a series of vowels and consonants. Shorter vowels described as V where as long vowels are described as VV.. which is due to a long vowel is known as biometric whilst short vowel recognized as mono-maric in Urdu. The six basic vowel templates (CV, CVC, CVV, CVCC, CVVC, and CVVCC) affects the vowel duration (10).

Acoustics is a discipline of physics concerned with sound and its waveform. "Acoustic phonetics" is the Branch of phonetics that studies the acoustic properties of speech sounds, including formant frequency, fundamental frequency, waveform amplitude, and time length on a spectrogram. Speech acoustics investigates both physical and psychological components of sound (11). Acoustic analysis on PRAAT investigate results in Frequency, Time Amplitude, and Formants. This work includes an objective assessment of the long and short vowels of the Urdu language. Short and long vowels will be objectively evaluated using PRAAT software, which will look at the formant frequencies F1 and F2 as well as the time duration. The time will be measured by looking at the waveform in milliseconds, and the formant frequencies F1 and F2 of the voice signal will be seen in the spectral data. Analyzing the appropriate millisecond duration Relatively minimal effort is required to modify the voice samples beyond simple time scale selections when compared to the study of spectral information, which provides more precise phoneme identification, for vowel recognition, formant transformation tracks focus on identifying the F1 and F2 frequencies; are the primary differentiators. Acoustics is a discipline of physics concerned with sound and its waveform. Speech acoustics investigates both physical and psychological components of sound (11). Acoustic analysis investigates spectrograms and time duration. Formant frequencies, pitch, intensity, and excitation patterns of sound (12). A study by Mashaqba B et al., revealed that HI with cochlear implantation revealed vowel formants nearer to those of normal hearing kids with large vowel space (13)

Keeping in view the high prevalence of HI, and cochlear implantation now being frequently done in Pakistan, the importance of the Urdu language, and the need for better speech therapy services, the current study was conceived to compare characteristics of vowe1 production in normal hearing typical Urdu-speaking children with hearing impaired children using Coch1ear Implants, focusing on time duration and first and second formant frequencies. The study is of significant importance since it might provide direction to speech-language pathologists for better rehabilitation services. By comprehending the complex effects of cochlear implants, therapists will be better equipped to tailor intervention techniques, effectively addressing the diverse acoustic challenges faced by children with implantation. This study may also provide valuable and thought- provoking insight for the broader field of cochlear implant research.

METHODS

This Comparative Cross-sectional study was conducted at Riphah International University Islamabad after permission of the Research Ethical Committee vide Ref: RCRAHS-ISB/REC/MS-SLP/01481 dated 21st Dec., 2022. Study was conducted over a period of 6 months from 1st January, 2023 to 30th June, 2024.

Sample included N= 36 children of both genders with 20 normally hearing children & 16 hearing impaired children using cochlear implant with hearing age of 2 to 5 years, Urdu as their primary language, on single sentence level, and receiving speech language therapy. The typical children that were included were those with Urdu as their primary language and were on single sentence level. Both genders were included in the study. Children with hearing aids and with any Co-morbid conditions were excluded.

The sample size was calculated using Epitools online calculator. The participants were recruited from Islamabad Model School, Islamabad, and well Being Rehabilitation Center Rawalpindi.

The study was divided into two phases:

Phase I: In this phase, a questionnaire was developed through a literature review. 33 items were included in the questionnaire. Sentences were made with the vowels taken from the CLE List of Urdu Vowels. 3 short vowels (/ɪ/, /ə/, /ʊ/) and 8 long vowels (/ɜ:/, /i:/, /o:/, /ɑ:/, /u:/, /e:/, /ɔ:/, /æ/) were used to build words. Content validity was done on four parameters (Relevance, Clarity, simplicity, and ambiguity). The content validity index was calculated following a review by eight experts on each item. CVI values $\geq$ 0.83 were considered acceptable. Each of these items was rated by eight experts i.e. Speech Language pathologist with clinical experience of at least two years of working with cochlear implant children, and teaching experience of at least 2 years of linguistic and phonetic and phonetic transcription were included in the study. The items were rated on a 4-point rating scale. Relevance of 3 or 4 was scored as 1 and 1 or 2 was scored as 0.

Informed consent letters were given before data collection, to the guardians/heads of the institutions and briefed about the study, including a statement that indicated the purpose and procedures of the research. Demographic data was collected from guardians. Sentence assessment from children was analyzed by a self-developed tool based on 33 sentence items that included vowels taken from "CLE list of Urdu vowels", with pictorial display in the form of flash cards. Speech samples were collected from children by using microphones to record audio files, to ensure optimal recording quality, during the recordings; participants were seated in a comfortable manner, while a small microphone was carefully positioned at a fixed distance of 4–10 cm from their mouth. The microphone was angled between 45° and 90° to ensure the best possible acoustic recording to analyze on PRAAT. Those files were then converted into MP3 and WAV format to read from a disk

sound file in the form of curves, wave form for graphical representation. All the data collected from during assessment was coded to protect the identity of the participants and was strictly restricted to disclosed to anyone.
In this study the assessment of short vowels and long vowels on PRAAT, the researcher checked the Formant F1, Formant F2, in HZ and Time duration in milliseconds (ms). In ms, short vowels are measured less than 60 ms, and long vowels are above 60 ms (14).
Collected data was then analyzed through PRAAT toolkit software. Time duration, formant frequency F1 and formant frequency F2 were measured from each sentence. After wards; the data obtained from analysis by PRAAT was further analyzed by SPSS version 25 for statistical findings in which formant frequency F1, formant frequency F2 and time duration were obtained.

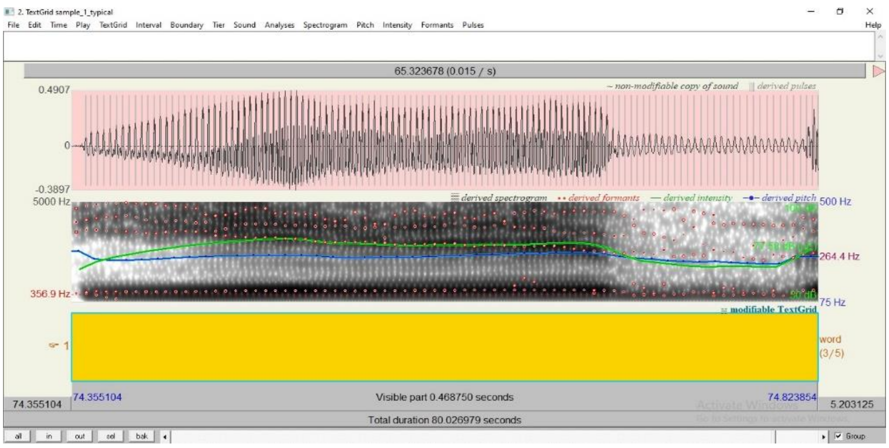

Figure 1: PRAAT sound window with waveform

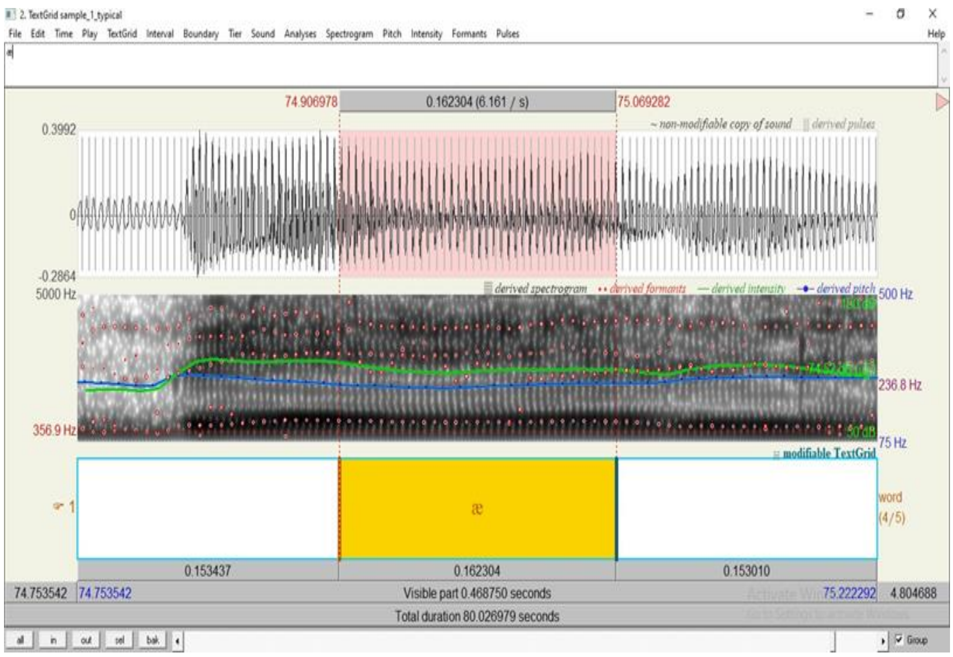

Figure 2: PRAAT sound window analysis of time duration and Formant Frequencies

Result:
The majority 58.3% of the sample had a hearing age of 3 years, followed by 30.6% with a hearing age of 2 years, and the remaining 11.1% with a hearing age of 4 years. 16.7% of children were receiving speech therapy for the last 2 years, 22.2% from 3 years and 5.6% children were receiving Speech therapy for the last four years.
The content validity index was calculated after the 8 experts' reviews of each item on a 4-point rating Likert scale. Relevant 3 or 4 on the rating scale were scored as 1 and no relevant was scored as 0. Only one item was deleted from the questionnaire it was not relevant to the study whereas 6 items were modified. The content validity Index (CVI) was 0.95.
To study the Acoustic characteristics of short and long Urdu vowels, time duration and formant frequencies 1 and 2 were calculated. The results are depicted in tabular forms.

Table 1: Mean and standard Deviation of Time Duration of Short Vowels of Urdu speaking Typical and Atypical Children

Group of subjects		Time Duration in Seconds (Sec)				
		Typical Children		Atypical Children		Sig.
Short Vowels		Mean (Sec)	SD	Mean (Sec)	SD	
ɪ	R1	0.040	0.007	0.045	0.008	.854
	R2	0.041	0.008	0.044	0.008	.942
	R3	0.041	0.008	0.046	0.009	.488
ə	R1	0.044	0.008	0.047	0.017	.095
	R2	0.045	0.008	0.049	0.013	.113
	R3	0.043	0.007	0.05	0.013	.021
ʊ	R1	0.049	0.009	0.047	0.009	.993
	R2	0.047	0.009	0.048	0.009	.906

Table 2: Mean and standard Deviation of Time Duration of Long Vowels of Urdu speaking Typical and Atypical Children

Group of subjects		Time Duration in Seconds (Sec)				
		Typical Children		Atypical Children		Sig.
Long Vowels		Mean (Sec)	SD	Mean (Sec)	SD	
ɔ:	R1	0.088	0.127	0.057	0.005	.063
	R2	0.059	0.006	0.059	0.006	.630
	R3	0.060	0.006	0.061	0.005	.398
i:	R1	0.096	0.013	0.107	0.015	.272
	R2	0.103	0.020	0.114	0.016	.393
	R3	0.104	0.022	0.114	0.016	.113
o:	R1	0.058	0.006	0.071	0.017	.011
	R2	0.058	0.006	0.074	0.020	.009
	R3	0.059	0.006	0.077	0.020	.012
ɑ:	R1	0.094	0.009	0.098	0.015	.173
	R2	0.099	0.015	0.098	0.012	.432
	R3	0.097	0.012	0.099	0.014	.454
ɜ:	R1	0.088	0.009	0.091	0.012	.847
	R2	0.089	0.011	0.093	0.012	.640
	R3	0.089	0.124	0.096	0.013	.857
u:	R1	0.079	0.006	0.090	0.012	.187
	R2	0.081	0.006	0.094	0.014	.168
	R3	0.082	0.006	0.094	0.014	.115
e:	R1	0.050	0.006	0.062	0.009	.035
	R2	0.051	0.005	0.063	0.008	.034
	R3	0.053	0.005	0.063	0.008	.008
æ	R1	0.059	0.004	0.060	0.010	.001
	R2	0.061	0.004	0.061	0.010	.001
	R2	0.061	0.004	0.062	0.009	.000

The time duration of short and long vowels in typical and atypical children were recorded at three separate instances (R1, R2, and R3) and displayed in milliseconds (Ms). For short vowel ɪ there were no statistically significant variations were seen in time duration between typical and atypical children across R1, R2, and R3 (p-values > 0.05). There were notable distinctions in the duration of /ə/ and /ï/ between children who were atypical and those who were typical were observed. These differences were statistically significant at R2 (p = 0.001) and R1 (p = 0.150), but not at R1 or R3. Hence, there were no appreciable changes in time duration for the short vowel /ɪ/ between children who are typical and those who are atypical. Nonetheless, notable significant variations exist at particular points in time for the vowels /ə/ and /ï/, indicating differences in the duration of these sounds between the two sets.

Table 3: Mean and standard Deviation of Formant Frequency 1 of Short Vowels of Urdu speaking Typical and Atypical Children

Group of subjects		Formant Frequency 1 (Hz)				
		Typical Children		Atypical Children		P-value
Short Vowels		Mean (Hz)	SD	Mean (Hz)	SD	
ɪ	R1	469.50	16.13	547.69	41.73	.049
	R2	469.78	16.06	554.04	45.49	.000
	R3	475.64	13.24	554.04	48.41	.004
ə	R1	671.36	32.65	783.11	57.37	.017
	R2	675.42	30.78	777.08	60.88	.024
	R3	675.42	32.60	776.57	84.58	.066
ʊ	R1	396.81	16.20	569.17	81.87	.000
	R2	396.79	19.75	559.84	85.48	.000
	R3	400.79	17.09	564.17	78.14	.000

The formants for short vowels were presented in (hz). There were considerable variances in the formant 1 for the vowels /ɪ/ and /ə/ at three instances (R1, R2, R) when comparing children with cochlear implant with normal hearing. Furthermore, at R1 ($p = 0.017$), R2 ($p = 0.024$), and R3 ($p = 0.066$), marginally significant changes were observed. The results discovered significant variations in F1 for /ʊ/ between children who were atypical and those who were typical, suggesting unique acoustic traits in the generation of vowels in each group. These variations are true for all three responses (R1, R2, R3).

Table 4: Mean and standard Deviation of Formant Frequency 1 of Long Vowels of Urdu speaking Typical and Atypical Children

Group of subjects		Formant Frequency 1 (Hz)				
		Typical Children		Atypical Children		P-value.
Long Vowels		Mean (Hz)	SD	Mean (Hz)	SD	
ɔ:	R1	586.03	11.43	644.24	94.54	.000
	R2	584.61	5.97	657.33	91.48	.000
	R3	583.94	7.72	656.63	81.17	.000
i:	R1	274.94	13.80	386.56	59.27	.000
	R2	274.80	14.91	383.84	53.01	.000
	R3	274.33	12.61	384.15	57.56	.000
o:	R1	412.71	12.67	559.66	80.84	.000
	R2	424.18	28.28	560.93	72.09	.000
	R3	429.05	24.46	554.35	74.88	.000
ɑ:	R1	699.71	11.73	701.48	59.06	.000
	R2	701.06	11.99	705.19	59.93	.000
	R3	704.10	10.18	704.29	57.59	.000
ɜ:	R1	620.94	6.62	687.52	57.18	.000
	R2	628.70	5.17	675.19	63.44	.000
	R3	637.11	9.43	688.07	49.96	.000
u:	R1	313.12	7.95	473.20	56.46	.000
	R2	314.56	5.611	479.88	69.25	.000
	R3	317.02	6.71	473.09	62.60	.000
e:	R1	420.47	10.24	544.62	70.74	.000
	R2	425.06	12.24	553.15	69.36	.000
	R3	424.10	12.21	565.65	99.15	.001
æ	R1	712.68	6.28	769.79	83.50	.000
	R2	716.16	8.99	779.57	77.11	.000
	R2	712.25	25.43	776.95	81.71	.000

Substantial variations in formant frequency 2 between atypical and typical children for the vowels /ɔ:/, /i:/, and /o:/ were observed. At response 1,2 and 3 (p-values: 0.020, 0.005, 0.007) was observed for vowel /ɔ:/. These discrepancies point to steady and noteworthy disparities in formant frequency 2 between the two groups. Additionally, the study discovered that there were significant differences between the two groups in formant frequency 2 for vowel /o:/ and /i:/. Significant variations in formant frequency 2 for /ɜ:/, /u:/, /e:/ and /æ/ were observed at all three occurrences (R1, R2, R3) between (NH) and (CI) children. These variations were substantial. For vowel /u:/ statistically significant changes were seen at R1 and R3 as (p-values: 0.001), and marginally significant differences were seen at R2. For /eː/ (p-values: 0.003), there were no discernible variations at R2 or R3 for vowel /eː/.

Table 5: Mean and standard Deviation of Formant frequency 2 of Short Vowels of Urdu speaking Typical and Atypical Children

Group of subjects		Formant Frequency 2 (Hz)				
		Typical Children		Atypical Children		Sig.
Short Vowels		Mean (Hz)	SD	Mean (Hz)	SD	
ɪ	R1	2139.58	61.96	2248.21	60.67	.533
	R2	2130.78	59.96	2251.09	54.97	.742
	R3	2144.60	50.84	2258.34	59.55	.830
ə	R1	1444.25	23.94	1560.66	87.15	.000
	R2	1443.20	23.99	1569.40	83.43	.000
	R3	1446.24	23.94	1568.70	80.84	.000
ʊ	R1	922.04	14.81	1018.91	47.54	.004
	R2	924.69	11.25	1015.29	12.25	.003
	R3	926.84	9.21	1027.24	12.50	.000

Table 6: Mean and standard Deviation of Formant Frequency 2 of Long Vowels of Urdu speaking Typical and Atypical Children

Group of subjects		Formant Frequency 2 (Hz)				
		Typical Children		Atypical Children		Sig.
Long Vowels		Mean (Hz)	SD	Mean	SD (Hz)	
ɔː	R1	849.77	26.12	1006.89	76.37	.020
	R2	847.26	21.35	1002.51	70.80	.005
	R3	849.48	20.04	1008.99	66.07	.007
iː	R1	2264.10	20.81	2305.33	43.77	.000
	R2	2264.42	21.13	2313.45	50.14	.000
	R3	2266.25	20.00	2314.69	49.95	.000
oː	R1	835.59	13.41	981.76	67.73	.000
	R2	836.33	15.40	985.69	64.95	.000
	R3	837.56	14.59	987.60	62.56	.000
ɑː	R1	1074.75	16.03	1105.69	53.16	.000
	R2	1075.75	16.45	1107.75	54.66	.000
	R3	1075.96	16.83	1110.25	52.42	.000
ɜː	R1	1415.01	18.26	1440.69	75.82	.000
	R2	1418.63	16.43	1444.72	84.20	.000
	R3	1422.68	16.17	1443.37	80.64	.000
uː	R1	867.95	14.88	947.71	58.73	.001
	R2	871.65	14.87	940.19	55.52	.003
	R3	873.42	16.68	947.71	53.39	.001
eː	R1	1799.65	23.83	1911.57	40.35	.074
	R2	1806.14	32.70	1917.48	37.60	.696
	R3	1804.41	22.12	1913.27	35.10	.266
æ	R1	1634.01	18.24	1680.92	73.85	.000
	R2	1634.72	17.54	1685.59	73.22	.000
	R2	1636.41	18.32	1681.34	81.17	.000

DISCUSSION

The current study revealed a significant difference in the duration of vowel /ə/ among children with atypical patterns, with a p-value ranging from 0.113 to 0.021. This highlights the distinct ways in which atypical children may produce this particular vowel compared to their typical counterparts. However, there are no significant differences in the duration of /ɪ/ and /ʊ/ between cochlear implant children and those with normal hearing, suggesting that the implant may not have a major effect on the time duration of these vowels. However, for longer vowels (/ɔː/, /iː/, /oː/, /ɑː/, /ɜː/, /uː/, /eː/, /æ/), there were statistically significant differences ($p<0.005$) in the production of /oː/ at both R1 and R3 for children with a cochlear implant. Additionally, significant differences were observed in the production of /e/ and /æ/ across all responses between children with normal hearing and those with a cochlear implant. No significant discrepancies in the duration of vowels (/ɔː/, /iː/ /ɑː/, /ɜː/, /uː/) for children with cochlear implants were noted. However, these variations imply that these vowels may have an impact on the duration and articulation control of these children. Analyses of both short and long vowels suggest that there is no conclusive evidence of a significant difference in duration between children with normal hearing and those with cochlear implants (15). Another study revealed a noteworthy difference in formants between CI and NH children, with longer acoustic deviations and greater variability of vowel categories and formant trajectories in the Cochlear Implanted group. In addition, the recognition accuracy of vowel sounds produced by CI children was significantly lower than that of their Normal Hearing peers. Hence, this study indicates notable dissimilarities in the first formant frequency of short vowels across children with cochlear implants, implying that these sounds are produced with distinct acoustic patterns. Such variations in formant frequency 1 may be attributed to changes in the vocal tract's topology, which could be influenced by the use of cochlear implants. Additionally, consistent and substantial alterations in the first formant frequency were found for all long vowels, further indicating that children with cochlear implants produce these sounds with distinctive acoustic characteristics. These changes may be a result of modifications to the movements of the lips and tongue, which in turn affect the resonance frequencies of the vocal tract (16).

In a recent study, researchers delved into the acoustic and perceptual qualities of vowel production in Arabic-speaking Jordanian children 7-11 years, who utilize cochlear implants. The team employed PRAAT analysis, a sophisticated acoustic software, to measure formant frequencies and pinpoint any perceptual inaccuracies in vowel production. The findings revealed significant disparities in formant frequencies among the groups, with the children using cochlear implants exhibiting higher frequencies compared to their age-matched peers with normal hearing. The perceptual analysis uncovered noteworthy differences between children with cochlear implants and those without. The F1 values for /i:/, /o:/, and /u:/ were considerably higher for the former group, while the F1 values for /e:/ and /a:/ were marginally lower. These findings hold significance for both speech therapy interventions and the assessment of language skills in Arabic-speaking children with cochlear implants. The study emphasizes the importance of tailoring speech therapy to fit the unique needs and capabilities of each child (17).

In Spain, a recent study explored the vowel production abilities of Spanish-speaking children with cochlear implants and revealed significant differences in F2 values between the two groups. This research sheds light on the unique challenges faced by atypical children and how understanding their vocal abilities can aid in their development. Furthermore, the current study analysis also took into account subtle variations in vowel articulation. Specifically, we found significant changes in formant frequency 2 for the short vowels /ə/ and /ʊ/. These findings suggest that cochlear implants could potentially lead to complex spectral adjustments, causing a rearrangement of the vocal tract's resonance. Interestingly, our study also revealed considerable differences in formant frequency 2 for long vowels (/ɔː/, /iː/, /oː/, /ɑː/, /ɜː/, /uː/, /eː/, /æ/) between atypical children and those with normal hearing (18). This suggests potential alterations in resonance patterns among children with hearing impairments.

Multiple studies have consistently demonstrated significant variations in the acoustic properties of vowel sounds produced by children with cochlear implants (13). This emphasizes the need to consider a range of acoustic factors in assessing the impact of these implants on speech production, providing valuable insights for researchers, SLP's and audiologists working with atypical populations. The study's findings demonstrated a significant impact of cochlear implants on the acoustic properties of vowel production in Urdu speakers. Particularly, there were distinguished disparities in both temporal aspects such as duration and spectral attributes like formant frequencies. In-depth knowledge of these differences could help to develop rehabilitative therapeutic strategies in context of speech disorders, managing articulatory movements associated with specific vowel sounds to improve the naturalness of speech. These findings underscore the multifaceted influence of cochlear implants on the intricate dynamics of speech production.

CONCLUSION

In Urdu-speaking children, discernible differences in formant frequencies 1 and 2, are present between normal-hearing children and those with cochlear implants. The varying sound patterns of the vocal tract illustrate the impact of cochlear implants on vowel pronunciation. These implants significantly influence the spectral aspects of speech, making it critical for a thorough assessment approach to consider both temporal and spectral factors in therapy.

Further research could delve deeper into the mechanisms driving these sonic differences, while also considering the potential impact of language and culture on the effectiveness of cochlear implants.

REFERENCES

1. Khamparia A, Gupta D, Nguyen NG, Khanna A, Pandey B, Tiwari P. Sound classification using convolutional neural network and tensor deep stacking network. IEEE Access. 2019 Jan 8;7:7717-27.
2. Diehl RL, Lindblom B. Explaining the structure of feature and phoneme inventories: the role of auditory distinctiveness. InSpeech processing in the auditory system 2004 (pp. 101-162). Springer, New York, NY.
3. Hockett CF. Der Ursprung der Sprache: Strukturmerkmale menschlicher und tierischer Kommunikationssysteme und ihr Stammesgeschichtliches .Alter.(Org.: The origin of speech. Scientific American, 203, 88-96. Übersetzt u. hrsg. von Schwidetzky, I. Über die Evolution der Sprache, S. 135-150). Frankfurt: Fischer. 1960.
4. Pisoni DB. Auditory short-term memory and vowel perception. Memory & Cognition. 1975 Jan;3(1):7-18.
5. Pane A. PHONEMIC NOTATION AND VOWEL. FOCUS PENDIDIKAN BAHASA INGGRIS. 2020 Apr 10;1(1):16-21.
6. McCombs CJ. The Acoustic Properties of Vowels: A Tool for Improving Articulation and Comprehension of English. InForum on Public Policy Online 2006 (Vol. 2006, No. 1, p. n1). Oxford Round Table. 406 West Florida Avenue, Urbana, IL 61801.
7. Nazir A, Dar YR, Lone ZB, Ahmed M. A Comparative Study of Formant Structures of Vowels in Kashmiri and Urdu. Interdisciplinary Journal of Linguistics. 2019;12:73-85
8. Dierickx J, Van Noppen JP. Crystal (David). The Cambridge Encyclopedia of Language. Revue belge de Philologie et d'Histoire. 1989;67(3):614-6.
9. Khana TA. Phonemic variations in similar words of Turkish and Urdu language. Journal of Language and Linguistic Studies. 2021 Jan 1;17(S1):517-33.

10. Ghazali MA. Urdu syllable templates. Annual Report of Center for Research in Urdu Language Processing (CRULP). 2002.
11. Barbone SK. Borden, GJ and Harris, KS Speech Science Primer: Physiology, Acoustics and Perception of Speech. Williams & Wilkins, Baltimore/London. 1980. Daniloff, R., Schuckers, G. and Feth, L. The Physiology of Speech and Hearing: An Introduction. Prentice-Hall, Englewood Cliffs, New Jersey. 1980. Pickett, JM The Sounds of Speech Communication: A Primer of Acoustic Phonetics and Speech Perception. University Park Press, Baltimore. 1980. Journal of Phonetics. 1982 Apr 1;10(2):225-9.
12. Bauman-Waengler J. Articulation and phonology in speech sound disorders: A clinical focus. Pearson; 2015 Jan 29.
13. Mashaqba, B., Huneety, A., Al-Khawaldeh, N. et al. Acoustics of long vowels in Arabic-speaking children with hearing impairments. Humanit Soc Sci Commun 10, 267 (2023). https://doi.org/10.1057/s41599-023-01778-9
14. Fatima N, Aden R. Vowel Structure of Urdu. Retreived from http://crulp.org/Publication/Crulp_report/CR03_13E.pdf. 2003.
15. Naeem MA, Raza MA. Acoustic analysis of vowel production in Urdu-speaking children with hearing loss. Pak J Otolaryngol. 2017;33(3):55-60.
16. Singh M, Basu S. Spectral analysis of vowel production in Hindi-speaking children with cochlear implant. Int J Pediatr Otorhinolaryngol. 2017;97:72-77.
17. Loizou PC. Introduction to cochlear implants. IEEE Engineering in Medicine and Biology Magazine. 1999 Jan;18(1):32-42.
18. Boersma P, Van Heuven V. Speak and unSpeak with PRAAT. Glot International. 2001 Nov;5(9/10):341-7.