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Acoustic Characteristics of Speech in Fante Speakers with Hearing Loss

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Abstract
Objective: The study compared the acoustic characteristics of speech in Fante speaking school children with moderately severe to profound sensorineural hearing loss to those with normal hearing. Method: Participants were Ghanaian students aged of 10 to 20, with or without hearing loss. Speech samples of monosyllabic words were recorded in an acoustically treated room. Analysis focused on the duration, voice onset time (VOT), and intensity of plosive sounds. Results: Consonant production of participants varied between individuals with and without hearing loss, especially for specific plosives. Participants with normal hearing had slightly longer voicing patterns compared to those with hearing loss. Participants with hearing loss consistently produced speech with higher maximum intensity values. Notably, /k/, /b/, and /g/ were observed to have the highest intensity values among the sounds. Conclusion: Hearing loss significantly alters the acoustic properties of speech. Individuals with moderately severe to profound sensorineural hearing loss exhibit distinct patterns in speech production that affect VOT, and intensity of consonant articulation.

Keywords: Fante, Hearing Loss, Acoustic Characteristics, Voice Onset Time, Consonants

1. Introduction

Hearing loss influences the developmental journey of children in their acquisition of language and communication skills (Cruzatti et al., 2022: Granlund et al., 2018; Granlund, 2015). Specifically, hearing loss affects children's ability to perceive and reproduce auditory stimuli in their surroundings (Verhoeven et al., 2016). Children with hearing loss experience both acoustic and linguistic barriers to communication (Granlund et al., 2018; Granlund, 2015).

Studies have reported voicing errors by individuals and children with hearing loss (Granlund et al., 2018; Granlund, 2015; Shojaei et al., 2016). For example, Shojaei et al. (2016) observed that prelingually deaf children have obvious problems in the production of consonants and vowels; while Granlund et al. (2018) hold that such children experience both acoustic and linguistic barriers in communication. More specifically, these difficulties are seen in areas such as substitution, neutralization, prolongation, and diphthongization (Shojaei et al., 2016; Sreekumar et al., 2024; Verhoeven et al., 2016); resonance problems, strain, unpleasant quality of voice, high pitch voice, altered breathing pattern, and utterance with excessive vibration (Baudonck et al., 2010; Narasimhan & Nataraja, 2019). These notwithstanding, although these children can accurately produce several isolated phonemes, they struggle to combine them into continuous speech, leading to reduced speech intelligibility (Sreedevi & Mathew, 2022).

Children's phonological development is influenced by how often each speech sound or phoneme appears in their specific language (Sreedevi & Mathew, 2022). For the school-going child with hearing loss, this can be more challenging in the classroom situation. According to Shojaei et al. (2016), one effect of congenital hearing loss is that normal development of speech is affected, and therefore, children with hearing loss need to be taught speech skills that under normal circumstances will be acquired even unconsciously.

Although hearing loss is prevalent among children in Ghanaian classrooms, literature on the analyzes of the speech of children with hearing loss is virtually unavailable. While studies have explored various aspects of speech production in individuals with hearing loss (Shojaei et al., 2016; Sreedevi & Mathew, 2022; Verhoeven et al., 2016), similar studies on Ghanaian school children are rare. There remains a need to investigate and describe the speech patterns of Ghanaian children with hearing loss, with a focus on the acoustic parameters of plosive consonants. This is necessary in this era of inclusive education as practiced in Ghana to study the peculiar speech disorders of children with hearing loss in the Ghanaian school systems to facilitate management approaches to improve upon their speech.

The oral communication skills of children with hearing loss can be limited, with significant impact on social, educational, and career opportunities. Plosive consonants, including sounds like /p/, /b/, /k/, /g/, /t/, and /d/, play a role in speech articulation and are known to be particularly vulnerable in individuals with hearing impairment (Roohparvar et al., 2024). The ability to accurately produce and perceive these sounds is critical for speech intelligibility.

Fante is a prominent Akan language in Ghana, spoken particularly in the Central and Western regions. As part of the six major dialects of the Akan language, Fante holds a special cultural and historical significance. It serves as the primary language of communication for the Fante people and is also taught in Basic schools within the Central and Western regions (Ghana Statistical Service, 2021). The Fante language boasts a unique linguistic structure, with a rich vocabulary, tonal patterns, and a blend of native Akan elements along with influence from European languages, reflecting Ghana's complex history.

By comparing the speech of children with hearing loss to that of their peers with normal hearing, this study seeks to understand the extent to which hearing loss affects the articulation and acoustic characteristics of plosive consonants. This analysis not only shed light on the unique challenges faced by children with hearing loss but also offered insights into potential differences or similarities between their speech and that of typically developing children.

This study investigated the acoustic characteristics of speech of Fante-speaking school children with moderately severe to profound hearing sensorineural loss and compared them with children with normal hearing. The objective was to provide an analysis of their plosive consonant production and how hearing loss affects the duration, voice onset time (VOT), and intensity of specific speech sounds, particularly plosive consonants.

2. Methods

2.1. Participants

Participants were purposively handpicked based on their hearing history to be included in the study. Participants were recruited from the Center for Hearing and Speech Services (CHSS), University of Education in Winneba, Ghana. The study involved 20 participants aged between 10 and 20 years. This comprised two groups of 10 participants each. Participants in Group 1 had hearing within normal range as determined by pure tone audiometric thresholds (≤25 dB HL) at octaves .25 to 8 kHz. Group 2 involved 10 participants diagnosed with post-lingual moderately severe to profound bilateral sensorineural hearing loss. Both groups of participants were assessed at the CHSS. Each participant had lived with their hearing loss for 8 years and more.

Participants received audiological assessment at CHSS that included otoscopic examination, pure tone air conduction (at octave frequencies from 0.25 to 8 kHz), and bone conduction threshold testing (at octave frequencies from 0.5 to 4 kHz) in a soundproof booth to determine their hearing sensitivity. Following the audiometric evaluation, participants were seated in a quiet room and instructed by an audiologist about how the speech test/recording would be conducted. Each participant signed a consent form; minors had their parents sign on their behalf for their inclusion in the study.

2.2. Procedure

The recording of the speech material took place at CHSS, in a room with low ambient noise. Participants were asked to read words shown to them on cards (Table 1) and/or name pictures that were shown to them. Participants produced the words in Fante. The words were recorded onto KAYPENTAX software using a unidirectional external microphone connected to a laptop. Each participant was seated in a chair in front of the microphone during the recording. The microphone was 15 cm away from the participant’s mouth. Participants were instructed to read the words and say the picture names shown to them as clearly as they could using their natural voice effort. Participants were given several demonstrations and practice of the task before the actual recordings.

Table 1: Wordlist in Fante and their English meaning

S/N	Fante words	Meaning in English
1	Ba	Child
2	Baé	To part/separate
3	Bàm	To embrace, clasp (in welcoming)
4	B⊃	To strike
5	Boá	To help
6	Bra	Come
7	Brám	To overlay
8	Buá	Respond
9	Bua	To cover
10	Bu	To bend
11	Da	Sleep
12	Dam	To lie in
13	Dɛw	To flare, flame, blaze
14	Dɛw	Joy
15	Duá / Duïa	To sow/plant
16	d⊃m	To belong/ crowed
17	Dwa	Cut into pieces/cut up
18	Gyá	To accompany
19	Ká	To bite
20	Kõa	To bend, curve
21	kyɛ́	To keep long, to last or endure
22	kyɛ́,	To divide
23	Kyéa	A bending sideward or a sideward inclination of the head
24	Kyiá	Greeting, salutation
25	Mã	To give
26	Pá	Good
27	Piá	To push onward, press
28	Prǎ	To sweep with a broom
29	Sá	Dance

30	Soá	To carry on the head
31	Srá	To smear
32	Süá	To learn
33	Taá	To pursue, persecute
34	Twá	Cut
35	Weà	To creep, crawl

Otoscopic examination was performed on the day of testing, and all participants had clear external auditory canal and normal tympanic membranes bilaterally. This was followed by a standard pure-tone audiometric (PTA) air and bone conduction testing to establish the hearing status of participants using the modified Hughson-Westlake (10 dB down, 5 dB up) method. A calibrated Kamplex AD 27 clinical audiometer was used with a set of supraural headphones for the testing in an acoustically treated test room. The audiometer and headphones were checked for proper functioning before conducting each series of tests. All participants in Group 2 had pure tone behavioural thresholds ≥56 dB HL on the day of testing (moderately severe to profound sensorineural hearing loss) (De Sousa et al., 2022). Participants in Group 1 had thresholds ≤ 25 dB HL in both ears on the day of testing.

The categorization of hearing ability was calculated based on pure tone averages of scores obtained at three frequencies (0.5 kHz, 1 kHz, and 2 kHz): Normal hearing (PTA -10 to 25 dB HL), mild hearing loss (PTA 26 to 40 dB HL), moderate hearing loss (PTA 41 to 55 dB HL), moderately severe hearing loss (PTA 56 to 70 dB HL), and severe-to-profound hearing loss (PTA 71 to 91+ dB HL). Normal hearing was determined: Bilateral normal hearing (PTA ≤ 25 dB HL in both ears) and bilateral symmetric sensorineural hearing loss (SNHL) (PTA > 25 dB HL in both ears) (De Sousa et al., 2022).

2.3. Speech recording

All participants had their speeches recorded individually at CHSS in an acoustically treated room with minimal reverberation and ambient noise. The word list included 35 words written on a card with their corresponding picture where necessary. The speech items consisted of monosyllabic words with consonants in the initial positions. The word list was selected based on their familiarity and occurrence in everyday Fante and Ghanaian English. The sound files were recorded in mono (one microphone, one channel) using a high-quality microphone, with sounds digitized at 44.1 kHz and 16 bits as a wav file format, using digital recording equipment. The recording of the speech materials lasted between 30 to 60 minutes.

3. Results

Table 2 shows participants' demographics. For the participants with hearing loss (Group 2), 6 (60%) were males and 4 (40%) were females. The mean age of participants in Group 2 was 14.8 years (SD = 3.4). For the control group – participants with normal hearing - there was an even distribution, 5 (50%) each for both male and female; their mean age was 15.8 years (SD = 3.1).

Table 2: Participants' characteristics

Variables		**Normal hearing (n = 10)**	**Hearing loss (n = 10)**
		n (%)	n (%)
Gender	Male	5 (50)	6 (60)
	Female	5 (50)	4 (40)
Age (years)	Mean (SD)	15.8 (3.1)	14.8 (3.4)

3.1. Hearing thresholds of participants

Table 2 presents the hearing thresholds (dB HL) for participants in the hearing loss group across six frequencies. The details are described in terms of the minimum threshold (Min), maximum threshold (Max), and standard deviation (SD) values.

Table 2: Mean hearing thresholds of participants with hearing loss.

		Hearing threshold					
		250 Hz	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**8000 Hz**
Right ear	Min	60	70	75	70	65	45
	Max	90	95	100	110	100	100
	SD	9.8	8.4	8.3	12.4	10.3	15.5
Left ear	Min	60	75	80	75	75	70
	Max	90	100	105	105	110	95
	SD	9.5	7.8	7.8	9.1	10.7	9.1

For the right ear, the minimum thresholds range from 45 dB HL at 8000 Hz to 60 dB HL at 250 Hz, while the maximum threshold ranges from 90 dB HL to 110 dB at 2000 Hz. The highest standard deviation was 15.5 at 8000 Hz.

For the left ear, the minimum thresholds range from 60 dB HL at 250 Hz to 70 dB HL at 8000 Hz, while the maximum threshold ranges from 90 dB HL at 250 Hz to 110 at 4000 Hz. The SD was highest at 4000 Hz, 10.7.

3.2. Participants consonant duration

Table 3 and Figure 1 compares the duration of various consonant sounds produced by individuals with normal hearing to those with hearing loss. The duration was measured in milliseconds (ms) and included the following consonants: t, p, k, b, d, and g. The results revealed distinct patterns of duration changes across different consonants, suggesting variability in how hearing loss affected speech production.

One key observation was the variability in duration changes between normal hearing and hearing loss conditions. For instance, the consonant /t/ showed a slight decrease in duration from 58 milliseconds (ms) in normal hearing to 52 ms in individuals with hearing loss (Figure 1). In contrast, /p/ exhibited a substantial increase in duration, rising from 63 ms to 80 ms. Meanwhile, the consonant /k/ demonstrated a significant decrease from 141 ms to 62 ms. The voiced consonants /b/ and /g/ also showed reductions in duration from 140 ms to 123 ms and 164 ms to 144 ms, respectively. However, the consonant /d/ remained relatively stable, with a minimal change from 117 ms to 119 ms.

Additionally, there appeared to be a contrast between voiced and voiceless consonants. While voiceless consonants like /p/ and /k/ exhibited opposing trends in duration changes, voiced consonants like /b/ and /g/ tend to have moderately reduced durations. This contrast reflected differences in how individuals with hearing loss perceived and produced voiced versus voiceless sounds.

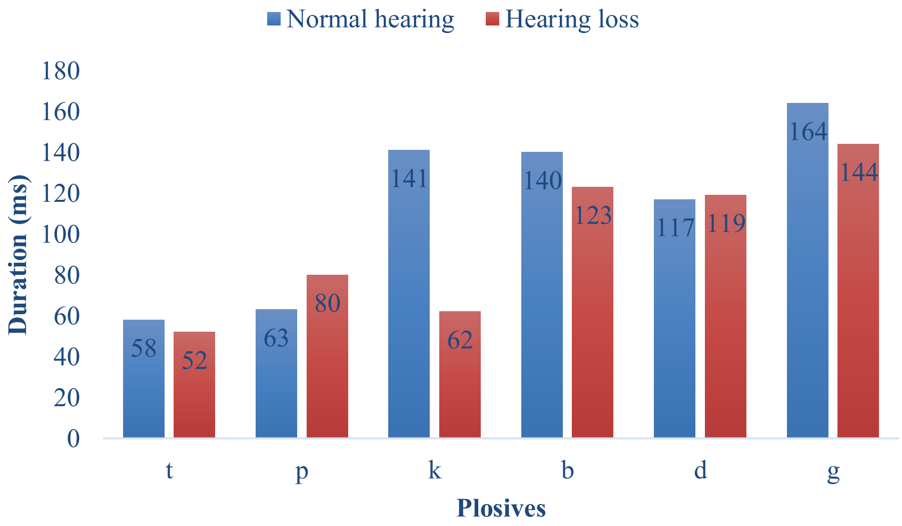

Table 3: Detail of participants consonant durations (ms).

Consonants	Duration normal	Duration hearing loss
t	58	52
p	63	80
k	141	62
b	140	123
d	117	119
g	164	144

The data presented showed VOT values for different speech sounds (consonants) in two groups: individuals with normal hearing and those with hearing loss. VOT is an important acoustic measure that represents the interval between the release of a consonant and the onset of vocal cord vibration, or voicing. Typically, positive VOT values indicated voiceless sounds, while negative values indicated voiced sounds. This data showed how hearing loss may affect speech production, particularly in terms of voiceless and voiced stop consonants.

For voiceless stops (/t/, /p/, /k/), there was a noticeable difference in VOT values between the two groups. The VOT for /t/ was slightly higher in the hearing loss group (12 ms) compared to the normal hearing group (9 ms). In contrast, the VOT for /p/ was lower in the hearing loss group (14 ms) compared to the normal hearing group (19 ms). Similarly, the VOT for /k/ was also reduced in the hearing loss group (23 ms) compared to the normal hearing group (34 ms).

For voiced stops (/b/, /d/, /g/), the data showed that individuals with hearing loss tend to produce these sounds with less negative VOT values compared to those with normal hearing. For instance, the VOT for /b/ in the hearing loss group was -85 ms, while it is -130 ms in the normal hearing group. Similarly, the VOT for /d/ was -102 ms in the hearing loss group, compared to -117 ms in the normal hearing group. The VOT for /g/ showed a slight difference as well, being -158 ms in the hearing loss group versus -163 ms in the normal hearing group.

Table 4: Voice onset time analysis of participants

VOT	Normal hearing	Hearing loss
t	9	12
p	19	14
k	34	23
b	-130	-85
d	-117	-102
g	-163	-158

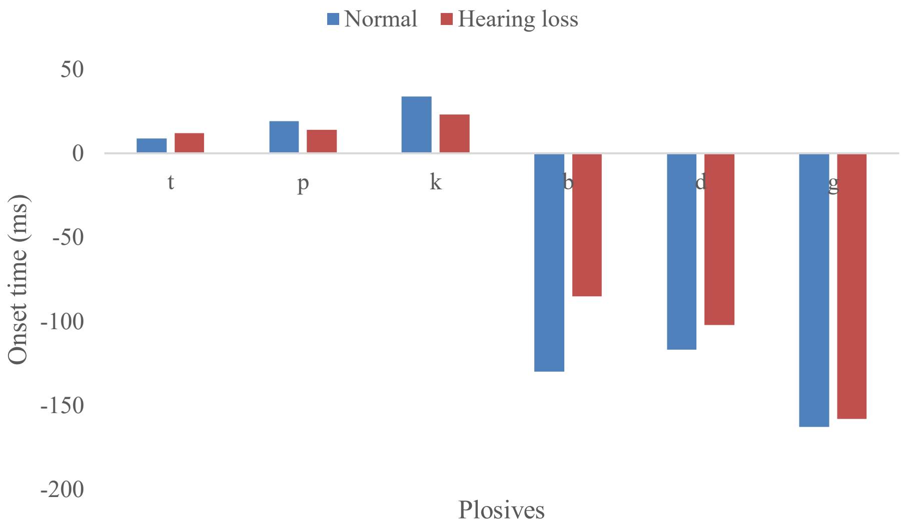

Figure 2: Graphical representation of participants' VOT

The data analysis indicated that the maximum intensity values for the participants with hearing loss are bigger in all the consonants studied than those for the participants with normal hearing. However, the differences between the intensity of /b/ for the hearing loss and the normal hearing participants were very small. For the participants with hearing loss, the plosives /k/, /b/, and / g/ have the highest intensity (68 dB) among the sounds, and this was followed by /t/, and /d/ 67 dB and then /p/ (65 dB) (Figure 3). For participants with normal hearing, however, the sound with the highest intensity was /b/, 67 dB and this was followed by /p/ 60 dB and then /t/ 59 dB then /d/, and /g/ (Table 5). Thus, for both the normal hearing and the hearing loss participants, /b/ was said with very high intensity.

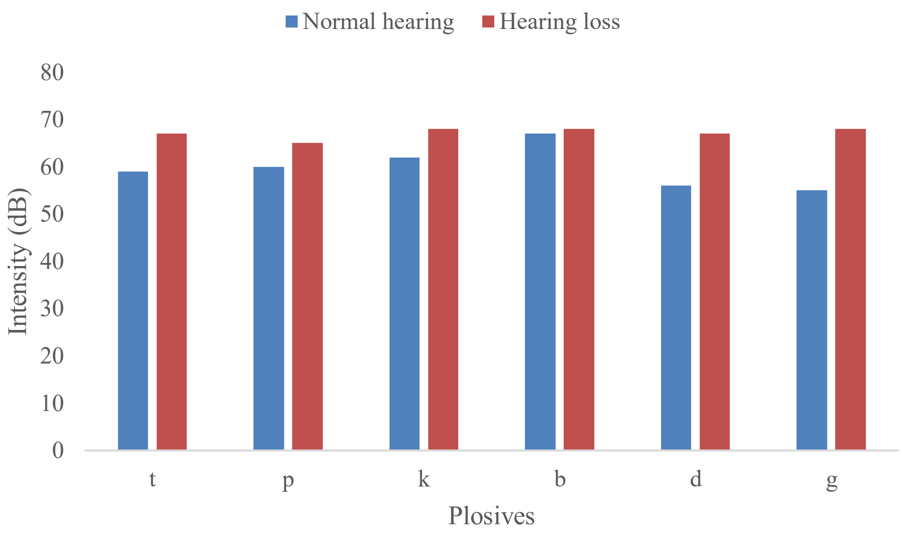

Figure 3: Intensity values of participants' speech

Table 5: Intensity values of participants in the production of plosives

Consonant	Normal hearing	Hearing loss
t	59	67
p	60	65
k	62	68
b	67	68
d	56	67
g	55	68

4. Discussion

The results highlighted the acoustic parameters of speech production among individuals with moderately severe to profound hearing loss compared to those with normal hearing. The discussion focused on the three key acoustic parameters: duration, VOT, and intensity, and how these parameters influenced speech patterns in both groups and the implications for effective communication.

4.1. Duration measurements

The study found variability in duration changes between normal hearing and hearing loss conditions. This variability can be attributed to differences in articulation patterns or compensatory strategies employed by individuals with hearing loss. Some consonants, such as /p/, showed increased duration because of stronger articulatory effort aimed at enhancing audibility. Conversely, reduced durations, as seen with /k/, might indicate challenges in maintaining articulation precision, possibly due to altered auditory feedback or motor adjustments. These findings have practical implications for hearing healthcare and rehabilitation, as they highlighted the importance of addressing articulatory inconsistencies when designing speech therapy programs and management strategies for individuals with hearing loss. By focusing auditory training programs aimed at enhancing consonant perception and production accuracy.

4.2. Voice Onset Time (VOT) analysis

Findings from the analysis of auditory patterns from both groups revealed subtle differences, with normal hearing participants generally showing slightly longer VOT values, especially for /p/ and /k/. This finding suggested that participants with hearing loss might face challenges in synchronizing voicing with articulation, potentially affecting speech clarity. Additionally, the velar plosive had the longest duration in VOT, followed by the bilabial plosive and then the alveolar plosive for both groups. This pattern suggested a tendency for shortened VOT in voiceless stops among individuals with hearing loss. The reduction in VOT may indicate that these individuals produced voiceless stops with reduced aspiration or a shortened voicing delay. This could be due to altered speech motor control or diminished auditory feedback. This pattern suggested that voiced stops are produced with a shorter pre-voicing duration in individuals with hearing loss, suggesting a weaker or delayed onset of voicing.

For voiced plosives, the differences in VOT values further reflected the impact of hearing loss, with normal hearing participants demonstrating earlier voicing onset, primarily due to their longer duration values for voiced plosives. It is observed that the voicing for the normal hearing participants started earlier than the voicing for participants with hearing loss, as the duration values for the voiced plosives were bigger for the normal hearing participants.

The data indicated that individuals with hearing loss tend to produce voiceless stops with shortened VOT and voiced stops with less negative VOT. This reflected altered motor control or impaired auditory feedback, resulting in changes to both aspiration and voicing characteristics. Verhoeven et al. (2019) observed that the speech characteristics differs in various ways of listeners with hearing loss from those with normal hearing. They (Verhoeven et al., 2019) further noted that a common problem in articulation of consonants involve voicing errors and places articulation errors.

4.3. Intensity Analysis

The analysis of intensity showed the role of hearing loss in modulating the intensity of speech sounds. Participants with hearing loss consistently produced speech with higher maximum intensity values in all consonants studied, with some exceptions, such as /b/, where differences were minimal. Similar findings have been reported, that individuals with hearing loss often have relatively high average pitch or speak in falsetto voice (Narasimhan & Nataraja, 2019). The plosives /k/, /b/, and /g/ stood out in terms of intensity, with the highest intensity values (68 dB) among the sounds. In the normal hearing group, /b/ was produced with the highest intensity, followed by /p/. This observation suggested that /b/ is consistently articulated with high intensity.

Complementarily, the audiometric results suggested elevated thresholds at higher frequencies (e.g., 4000 and 8000 Hz), with maximum thresholds reaching 100 dB and significant variability (SD of up to 15.5). Hearing loss within these frequency regions and at high thresholds can affect individuals' ability to perceive fine acoustic details of consonants, leading to difficulties in accurate production. This will have implications for speech intelligibility.

Additionally, speech production relied heavily on auditory feedback by the individual to monitor and adjust their own articulation (Scheerer & Jones, 2018). Individuals with thresholds at or above 60 dB across all frequencies may struggle to hear their own speech accurately (poor auditory feedback), particularly in the higher frequency consonant sounds. Again, for children with losses above 60 dB at high frequencies, this may result in delays in acquiring high-frequency consonant sounds, which are essential for clear speech development and articulation. Revathi and Sasikaladevi (2019) noted that children with difficulty perceiving high frequency sounds may struggle to hear sounds like "s". "t", and "shi", which are commonly used in everyday speech. Without these sounds, understanding sentences can become challenging. These difficulties may result in distorted articulation of plosives and stops, since these sounds require exact discrimination and feedback for proper placement and manner of articulation, resulting in articulation errors or substitutions (e.g., replacing /b/ with /p/). Jafari et al., (2016) also found that prelingually deaf children exhibited notable segmental errors in both consonant and vowel production, as well as suprasegmental deviations such as substitution, neutralization, prolongation, and diphthongization.

5. Conclusion

The study examined the effects of hearing loss on speech production among Fante speaking individuals aged 10 to 20 years by analyzing consonant duration, VOT, and intensity. Generally, the findings indicated that hearing loss significantly impacted the acoustic properties of speech in Fante speaking children. Children with hearing loss exhibited distinct patterns in speech production that affects VOT, and intensity of consonant articulation, highlighting the complexity of speech articulation and the challenges faced by individuals with hearing loss. Additionally, the study showed the role of auditory feedback in fine-tuning motor speech control. Clinically, the results highlighted the importance of early and continuous auditory rehabilitation in children with hearing loss to curb its impact on speech development.

6. Future research

Future research should consider longitudinal studies tracking the development of speech in Fante speaking children with hearing loss over time. This could provide useful information into the evolving nature of speech production in these children as they individuals grow and potentially adapt to interventions.

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