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Comparison of Acoustic Spaces of 9-year-old Cerebral Palsy and Normal Children

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***Abstract*— This study examines the acoustic features of vowels of four children who are 9 years old: two cerebral palsy (CP) and two normally developed. The voice samples from these children were collected using the picture-naming task and then analysed. Acoustic features like Formant frequencies (F1 & F2) and acoustic space of the vowels are examined. The study's findings indicated the following: 1. F1 is much developed in CP children as compared to F2; 2. the acoustic space area occupied by the vowels of the male CP child is more than the female child of the same age; 3. Further the acoustic space area of CP children is smaller than a typically developed children of the same age.**

***Keywords*— Cerebral palsy, formant, frequency, Acoustic space, vowel area, Hindi-speaking children.**

I. Introduction

"Cerebral palsy (CP) describes a group of persistent disorders of the development of movement and posture, causing activity limitations that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain" (Bax, M. 1964)

Communication difficulties can be associated with any type of Cerebral Palsy and may lead to limitation in production of movement for speech, gesture and facial expression. It may cause problems with expression as well as perception of speech. The prevalence of speech and communication impairment increases with the severity of motor and intellectual impairment.

In Cerebral Palsy, it becomes difficult to use the lips, tongue and jaw properly to make correct articulation making them dysarthric. Cerebral palsy has been regarded as the most common severe motor disability which causes non-progressive disturbances in the developing infant brain. (C. Lepage, L. Noreau, P. Bernard and P. Fougeyrollas, 1988). Vowels are central to the understanding of different acoustic features of speech. Different studies have proved that children achieve a high degree of vowel accuracy at a very early age. Therefore, the present study focuses on the vowel acoustic features in cerebral palsy children of 10 years.

II. Literature Review

Cerebral Palsy has been a topic of discussion among the doctors, therapists and speech analyst for a long time. Plenty of literature is available discussing the definition, types, causes and cure of cerebral palsy. There have been a few researches conducted to study the communication problem, methods used to improve communication, comprehension and acoustic studies of the speech of cerebral palsy individuals.

The research conducted by Marchant, J., Macauliffe, M. J. and Huckabee, M. L. on "13 years old child with severe dysarthria associated with spastic cerebral palsy demonstrated the importance of phonetic placement therapy (PPT) and sEMG-facilitated biofeedback relaxation therapy in improving articulation. The child was exposed to the two therapies for six weeks and then the outcome was measured using acoustic and perceptual analysis. The results showed significant improvement in single word articulation and intelligibility. However, the intelligibility at paragraph and sentence level did not change following either of the treatment. Significant changes were also observed in the acoustic analysis. The results showed that there were minimal changes in perception after the treatment. However, there was a significant increase in F2 frequency for /æ/ reflecting a subtle improvement in lingual range resulting from a vocal tract constriction and stabilization. There was also decrease in F2 for the vowel /u/ which might have been due to the improvement in lip-rounding occuring as a result of a reduction in labial muscle hyperfunction. These observation support the fact that sEMG treatment helps reduce labial muscle constriction."

Chen, et. al. (2010) "investigated the speech motor control in children with cerebral palsy using kinematic analysis. The data was collected from 10 children with mild CP aged between 4.8 to 7.5 years which formed the target group. The children underwent analysis of percentage of correct consonant and kinematic analysis of speech tasks i.e. poly-syllabic and mono-syllabic tasks. The results showed that cerebral palsy children showed greater spatiotemporal indexes in poly-syllabic task but not in the mono-syllabic tasks as compared to the target group. The children suffering with cerebral palsy had difficulty in processing increased articulatory demands. The other parameters like utterance duration, peak oral opening displacement and peak oral opening velocity of both the tasks do not show much difference between the cerebral palsy children and the control group." (Chen, 2010)

The study by Connaghan, K. P. and Patel, R. showed "how the production of vowels helps in intelligibility of individuals with motor speech problems. In adults with dysarthria the rate

reduction and increased loudness helps in improving the intelligibility due to change in vowel production. This study aims to provide data for perceptual and acoustic parameters from three cerebral palsy children (aged between 3 to 8 years) in four conditions: habitual, increased loudness, slowed rate and emphatic stress. Similar data was also collected from age-matched children who served as the control group. For each condition data was collected for the three corner vowels / i, a, u/ using audio-visual methods. The perceptual intelligibility of the vowels was based on the judgements made by 12 unfamiliar listeners. The acoustic analysis was done for the first two formants F1 and F2 which was further compared with variation across the four conditions. The results showed that there was increased F2 variance in case of cerebral palsy children. The prosodic strategies varied across speakers with two children demonstrating increased vowel intelligibility in at least one condition." (2013)

In the article "Acoustic studies of Dysarthric Speech: Methods, Progress and Potential", Kent, R. D. & Weismer, G., has given "an overview of the acoustic analysis of dysarthria. The paper summarizes important assessment tools of disordered speech and voice. This is an important topic both in research on dysarthria and the clinical use of acoustic analysis as a supplement to perceptual assessments. The paper also provides a list of possible measurements for various aspects of phonation, articulation and resonance as may be seen in neurologically disordered speech." (1999)

Lui Huei-Mei, Tsao Feng-Ming and Kuhl, P. K. "studied the effect of reduced vowel working space on intelligibility of speech in Mandarin speaking CP adults. The paper illustrates two experiments related to vowel working space. In experiment 1, the acoustic-perceptual relationship between vowel working space area and speech intelligibility is examined. The CP participants are made to read aloud 18 bisyllabic words at their normal speed. Each CP participant's words are then identified by three normal listeners. The percentage of correct vowels and words are identified and calculated as vowel intelligibility and word intelligibility respectively. The results showed that CP adults exhibited a smaller vowel working space as compared to the age matched control group which had a direct effect on the intelligibility of their speech. Experiment 2 examined if an expansion of the vowel working space improved the perception of the vowels. The result of the perceptual experiment was that the distortion of vowels by the CP adults formed a small acoustic space which led to shrunken inter-vowel perceptual distance for the listeners." (2005)

In another study, Chen (2012) examines "the acoustic variability in the speech of CP children. The data was collected from four 4-years-old Mandarin speaking children two with CP and two normal using picture-naming tasks and through spontaneous interaction with adults. The acoustic vowel space, pitch and speech rate was calculated from the data collected. The differences in vowel production were analyzed in three aspects: F1 and F2 values for the vowels / i, ɑ, u, ə, ɛ, ɔ/, standard deviation of formant frequencies and vowel space. Pitch values were studied in bi-syllabic or tri-syllabic words on four dominant tones: high-level, high-raising, low falling and high-falling tone. In order to study the speech rate the number of syllables per minute and the number of intelligible syllable per minute was calculated. The result of this study showed that children with CP have smaller vowel space and their formant frequencies are scattered. The CP children spend more time in producing the utterances and their speech tones were unstable. Further, both the rate of speech production and speech intelligibility is lower in CP children."

Thus, we see that many studies have been conducted to study the speech of cerebral palsy individuals. Vowel space or acoustic space of vowels plays an important role in the intelligibility of the vowels. In case of the CP individuals the disruption in vowel space, formant frequencies and other acoustic features causes speech problems. The production of vowels is further affected by the shape and size of the vocal tract in CP individual.

III. Methodology

A. The Participants

Two cerebral palsy children one male and one female of 9 years constitutes the target group (TG) of this investigation. Their acoustic features are matched with neurologically normal children of same age and gender which constitutes the control group (CG). All the participants have Hindi as their L1.

TABLE I
DESCRIPTIVE DATA OF TARGET GROUP

Subject Code	Age	Gender	Type of Cerebral palsy
CP3 9M	9	Male	CP Spastic Quadriplegia
CP4 9F	9	Female	CP Spastic Diplegia

TABLE II
DESCRIPTIVE DATA OF CONTROL GROUP

Subject Code	Age	Gender
N3 9M	9	Male
N4 9F	9	Female

B. Data Collection

The data from the target group was collected from an NGO where they visit regularly for physiotherapy. The data of the target group was collected from a government school.

The present study focuses mainly on the acoustic space of Hindi vowels. Recordings are made for the seven peripheral vowels /i, e, ɛ, ɑ, ɔ, o, u/ for Hindi. The words for data collection is selected from the children 's repertoire and a specific word list is prepared. Only those words are included in which the peripheral vowels occur between two stop consonant i.e. the vowel phoneme occurs in the CVC position.

TABLE III
LIST OF WORDS USED FOR THE STUDY

Vowels	Hindi word	IPA Translation	English word
/i/	□□□□□	/pəpitɑ/	Papaya
/e/	□□□	/peʈ/	Stomach
/ɛ/	□□□	/bɛʈ/	Sit
/ɑ/	□□□□□	/kitɑb/	Book
/ɔ/	□□□□	/cɔkɑ/	Four runs
/o	□□□□	/totɑ/	Parrot
/u/	□□□□	/pujɑ/	Worship

The above table gives a very comprehensive picture of the words used to collect speech samples with their IPA transcription and English meaning. In all the above words the vowel occurs in the word medial position between the stop consonants.

The subjects are made to articulate each of these vowels thrice. Sometimes for the cerebral palsy children more number of articulations were needed to be recorded for better analysis. This data is collected using the picture naming task. The children are made to identify the image on the picture and name them.

C. Case Studies

CP3 9M

CP3 9M is a nine years old male. He is a left-handed person suffering from CP Spastic Quadriplegia. He is a pre-mature born caesarian child. The mother had a history of a miscarriage and had normal pre-natal condition. The child had high fever just after birth for a few days.

The child had problems with locomotion. He could not stand or walk. He could sit maintaining his posture only for a few minutes. The child crawled on the floor to move from one place to another. The child used a walker and was totally dependent on the caretakers. The trunk of the child was weak and both the upper and lower parts of the body were stiff. The child went through regular physiotherapy sessions. The child had difficulty in achieving any voluntary control of his movement.

The mental ability of the child was good and had no vision or hearing problem. The child also had problems is controlling his neck in a straight position. The child had problems in bathing, dressing, grooming, etc. if could not hold the spoon with his hands and had to be fed by others.

The speech and communication skill of the child was average. He did make communication errors but his speech could be easily comprehended. The child could not hold air in his lungs for a long time and had difficulty in articulation.

During the data collection session, the child was very enthusiastic and followed the instructions without any problem. He articulated all the words thrice with a few articulation errors. He had no problem in naming the objects shown in the picture.

CP4 9F

CP4 9F is a nine years old female. She is a right-handed person suffering from CP Spastic Diplegic. She is a caesarian child and the mother had no pre-natal problem. During the first three years after birth the child had blood infection. The child has normal child and average mental ability.

The mobility of the child is totally hindered and the child can only crawl. She is unable to sit, stand and walk. She uses rollers as a moving aid. She can move around only with the help of a wheel chair. The child has difficulty is standing and walking due to uneven shape of the feet.

The speech and communication skills of the child are highly impaired. The child has both verbal and non-verbal communication behaviour. The child has problems articulating both vowels as well as consonants. The speech imitation skill of the child is very poor.

During the data collection session, the child is cooperative and understands the instructions given. The child makes a lot of articulation errors and her speech is highly difficult to comprehend. The child must put in a lot of effort to articulate and speak. The child continuously salivated which made articulation even more difficult.

D. Comparison of Acoustic Space of Cerebral Palsy and Normal Children

This section compares and contrasts the acoustic space of vowels of cerebral palsy and normal children of the same age and gender. Such an anlysis would help us understand the extend to which the cerebral palsy children have deviated in their articulation from neurologically normal children of the same age and gender. A comparison is made between the area of acoustic space used by cerebral palsy and normal children.

1) CP3 9M vs. N3 9M

In this section a comparison between the acoustic vowel space of CP3 9M and N3 9M has been made. CP3 9M is a nine years old male cerebral palsy child and N3 9M is a neurologically normal nine years old male child.

TABLE IV
FORMANT VALUES OF VOWELS OF CP3 9M AND N3 9M

Vowels	CP3 9M - F1	CP3 9M - (F2-F1)	N3 9M - F1	N3 9M -(F2-F1)
/i/	-548.114	-471.091	-338.428	-2052.57
/e/	-646.889	-751.809	-603.107	-1392.73
/ɛ/	-781.806	-667.101	-940.977	-761.905
/ɑ/	-959.952	-701.587	-841.567	-272.039
/ɔ/	-908.771	-470.883	-539.783	-440.572
/o	-719.82	-445.595	-372.853	-404.634
/u/	-518.547	-368.487	-337.885	-993.223

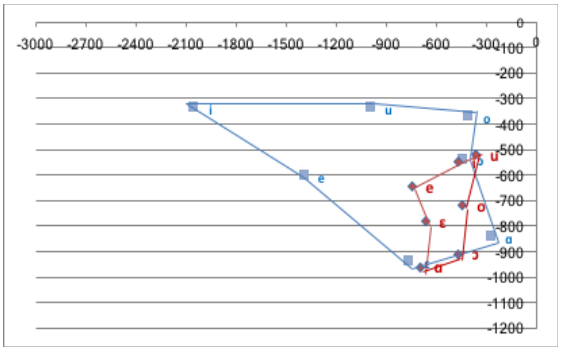

Fig. 1 Acoustic Space of CP3 9M and N3 9M

Discussion

CP3 9M has the lowest F1 value as -518.547 Hz and highest as -959.952 Hz. For F2-F1 we find the lowest as -368.487 Hz and highest as -751.809 Hz. The range for F1 is 441.405 Hz and for F2-F1 the range is 383.322 Hz. N3 9M has the lowest F1 value as -337.885 Hz and highest as -940.977 Hz. For F2-F1 we find the lowest as -272.039 Hz and highest as -2052.57 Hz. The range for F1 is 603.092 Hz and for F2-F1 the range is 1780.531 Hz.

If we compare the acoustic space area used by the two participants, the area occupied by CP3 9M is 89836.005904 whereas N3 9M uses an area of 566864.739764. If we calculate the percentage we can say that the acoustic vowel space area of CP3 9M is 15.84% of N3 9M.

In the case of CP3 9M both the front back and high low is not as developed as N39M which is a neurologically normal child of the same age and gender. The front close unrounded vowel /i/ is shifted back and occurs close to the back close rounded vowel /u/ in CP3 9M. N3 9M has higher values of both –F1 and –(F2-F1) as compared to CP3 9M. The vowels occupy a much wider area in case of N3 9M with the front-back and high-low distiction well established. The vowels of CP3 9M occupy a small acoustic space area but can be distinguished.

2) CP4 9F vs. N4 9F

In this section a comparison between the acoustic vowel space of CP4 9F and N4 9F has been made. CP4 9F is a nine years old female cerebral palsy child and N4 9F is a neurologically normal nine years old female child.

TABLE V
FORMANT VALUES OF VOWELS OF CP4 9F AND N4 9F

Vowels	CP4 9F	CP4 9F	N4 9F	N4 9F
	- F1	- (F2-F1)	- F1	-(F2-F1)
/i/	-545.703	-792.187	-337.885	-825.223
/e/	-568.873	-762.26	-338.428	-2332.57
/ɛ/	-589.4	-699.162	-803.107	-1560.73
/ɑ/	-595.917	-738.674	-940.977	-929.905
/ɔ/	-615.298	-663.529	-841.567	-272.039
/o	-857.989	-384.946	-539.783	-608.572
/u/	-554.882	-270.451	-372.853	-572.634

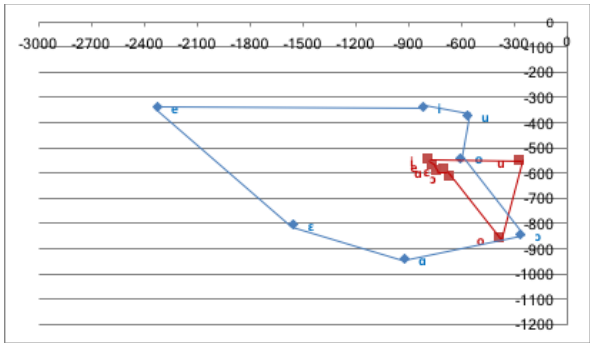

Fig. 2 Acoustic Space of CP4 9F and N4 9F

Discussion

CP4 9F has the lowest F1 value as -545.703 Hz and highest as -857.989 Hz. For F2-F1 we find the lowest as -270.451 Hz and highest as -792.187 Hz. The range for F1 is 312.286 Hz and for F2-F1 the range is 521.763 Hz. N4 9F has the lowest F1 value as -337.885 Hz and highest as -940.977 Hz. For F2-F1 we find the lowest as -272.039 Hz and highest as -2332.57 Hz. The range for F1 is 603.092 Hz and for F2-F1 the range is 2060.531 Hz.

If we compare the acoustic space area used by the two participants, the area occupied by CP4 9F is 71830.067066 whereas N4 9F uses an area of 761467.3677645. If we calculate the percentage we can say that the acoustic vowel space area of CP4 9F is 9.43% of N4 9F.

In the case of CP4 9F both the front back and high low distinction amongst the vowels is lost. The entire vowel pattern is distrupted. All the vowels have been misarticulated except the front close unrounded vowel /i/ and the back close rounded vowel /u/. It becomes very difficult to identify these vowels correctly when this cerebral palsy child articulates them. When compared to the vowel space of the neurologically normal child of the same age and gender it is seen that the cerebral palsy child makes a lot of articulation errors making her speech unintelligible. N4 9F has higher values of both –F1 and –(F2-F1) as compared to CP4 9F. The vowels occupy a much wider area in case of N4 9F with the front-back and high-low distiction very well established.

IV. CONCLUSIONS

Due to lack of motor muscle control CP children show substantial difference in speech production when comparing it with typically developing children. The CP children have low formant frequencies. The F1 is more developed has compared to F2. This means that the high-low contrast is better developed than the front-back contrast. The male CP child has a wider acoustic space area as compared to the female child of the same age. Furthermore, the vowel space of CP children is smaller than that of the neurologically normal child of the same age. These findings suggest that the

CP children have limited tongue mobility with small articulatory area.

The limitations in this preliminary study suggest directions for further research. The number of children included for analysis is limited. Further studies with more number of participants would yield more objective results. The analysis is made only based on data collected from 10 years old children. A detailed study on CP children of different ages would provide a much clearer picture.

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