Study of Acoustic Space of 6-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 6 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 analyzed. 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.*

Key Words: *Cerebral palsy, formant, frequency, Acoustic space, vowel area, Hindi-speaking children.*

1. 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, language 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.

2. 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 a 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.

3. METHODOLOGY:

The Participants

Two cerebral palsy children one male and one female of 6 years constitutes the target group (TG) of this investigation. Their acoustic features are matched with neurologically normal children of the same age and gender which constitutes the control group (CG). All the participants have Hindi as their L1.

The tables below show information about the TG and CG .

Table 1: Descriptive data of the target group

S. No.	Code	Age	Gender	Type of Cerebral Palsy
1	CP1 6M	6	Male	CP Spastic Quadriplegia
2	CP2 6F	6	Female	CP Spastic Quadriplegia

Table 2: Descriptive data of control group

S. No.	Code	Age	Gender
1	N1 6M	6	Male
2	N2 6F	6	Female

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.

The list of words used for the study has been given below in Table 3:

S.No.	Vowel	Hindi Word	IPA Transcription	English Meaning
1	/i/	पपीता	/pəpitɑ/	Papaya
2	/e/	पेट	/peʈ/	Stomach
3	/ɛ/	बैट	/bɛʈ/	Sit
4	/ɑ/	किताब	/kitɑb/	Book
5	/ɔ/	चौका	/cɔkɑ/	Four runs
6	/o	तोता	/totɑ/	Parrot
7	/u/	पूजा	/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.

Case Studies:

CP1 6M

CP1 6M is a six years old male. He is a right-handed person suffering from CP Spastic Quadriplegia. He is a caesarian child and the mother had respiration and B.P problem during the pre-natal condition. During the first three months of birth the child had difficulty with respiration and dehydration. Even till the age of six the child has problems with respiration and breathing.

He had normal vision and hearing with average mental ability. He is totally dependent on the caretakers for bathing, dressing and grooming.

The child cannot move without external help. He uses a wheel chair to move around. The child's trunk is weak and both the upper and lower part of the body suffers from tightness. The child is not able to write using a pen.
CP1 6M does not have any clarity in his speech. He speaks with a lot of articulation errors. But his speech is intelligible.

During the data collection session, the child was initially shy but later participated in the task enthusiastically. He had no difficulty in following the instructions given to him and identified all the pictures shown to him. He repeated each word thrice without any problem.

CP2 6F

CP1 6F is a six years old female. She is a right-handed person suffering from CP Spastic Quadriplegia. She is a normal born child and the mother had no pre-natal problem. The child has no congenital problems. During the first three years after birth the child suffered with high fever at one time.

The health of the child is good and has no hearing or vision defect. The child's mobility is partial and is mentally subnormal. The child has associated problem of dystonia in all the four limbs, in which the muscles have no tone and coordination. The child's trunk is weak and both the upper and lower part of the body has focal tightness.
The child cannot sit or stand without any support even for a few seconds. The right side of the child is especially a little weak. The child has a fear of loud noises and darkness. The child is not able to release, grasp or transfer objects with her hand.

The child's speech is highly impaired. The child has low motivation and has some behavior problems. The child doesn't communicate with unfamiliar people easily. She had a lot of problems in articulating tri-syllabic words.
During the data collection session, the child refused to cooperate. The child's caretaker had to be present and motivate the child continuously to speak. The child at times could not name the object in the picture and audio input had to be given. Due to lack of concentration of the child the data had to be collected in two different sessions.

Comparison of Acoustic Space of CP1 6M and CP2 6F

The two subjects CP1 6M and CP2 6F are of the same age i.e. six years but their acoustic spaces are very different. The male cerebral palsy child CP1 6M has a much well developed acoustic space as compared to the female child CP2 6F. Both the front back and high low contrast is better in case of the six years old male child. The acoustic space occured by CP1 6M is 60570.424140 and CP2 6F is 31974.186826. Further in case of the female child CP2 6F the vowel /ɑ/ is displaced and lies close to the front close unrounded vowel /i/. The data clearly shows that the female child shows more articulation problem as compared to the male child of the same age.

A Contrastive Analysis 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. The acoustic space area is calculated using the online Irregular Polygon Area Calculator which however does not give any unit. A comparison is made between the area of acoustic space used by cerebral palsy and normal children.

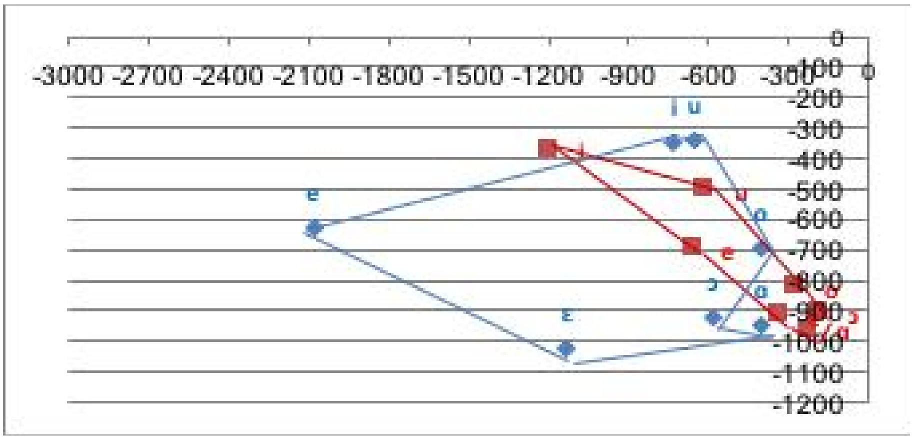
CP1 6M vs. N1 6M

In this section a comparison between the acoustic vowel space of CP1 6M and N1 6M has been made. CP1 6M is a six years old male cerebral palsy child and N1 6M is a neurologically normal six year old male child.

Table 4: Formant values of vowels of CP1 6M and N1 6M

Vowels	CP1 6M		N1 6M	
	- F1	- (F2-F1)	- F1	-(F2-F1)
i	-370.944	-1197	-348.46	-731.74
e	-693.889	-656.43	-627.44	-2081.8
ɛ	-917.032	-333.47	-1023.2	-1132.7
ɑ	-959.566	-227.22	-946.32	-400.72
ɔ	-906.202	-184.48	-923.18	-584.48
o	-820.756	-268.35	-694.6	-402.04
u	-500.309	-608.76	-343.06	-651.72

Figure 1: (Graph) Acoustic space of CP1 6M vs. N1 6M



4. DISCUSSION:

CP1 6M has the lowest F1 value as -370.944 Hz and highest as -959.566 Hz. For F2-F1 we find the lowest as -184.48 Hz and highest as -1196.99 Hz. The range for F1 is 588.622 Hz and for F2-F1 the range is 1012.51 Hz. N1 6M has the lowest F1 value as -343.063 Hz and highest as -1023.15 Hz. For F2-F1 we find the lowest as -400.715 Hz and highest as -2081.82 Hz. The range for F1 is 680.087 Hz and for F2-F1 the range is 1681.105 Hz.

If we compare the acoustic space area used by the two participants, the area occupied by CP1 6M is 60570.424140 whereas N1 6M uses an area of 663939.160405. If we calculate the percentage we can say that the acoustic vowel space area of CP1 6M is 9.12% of N1 6M.

In the case of CP1 6M both the front back and high low distinction is not as well developed as compared to the normal child of the same age and gender. The front open-mid unrounded vowel /ɛ/, back open unrounded vowel /ɑ/, back open-mid rounded vowel /ɔ/ and back close-mid rounded vowel /o/ occur close to each other. N1 6M has higher values of both –F1 and –(F2-F1) has compared to CP1 6M. The vowels occupy a much wider area in case of N1 6M with the front-back and high-low distiction well established. In case of CP1 6M vowels occupy a small acoustic area with little articulatory distiction amongst themselves.

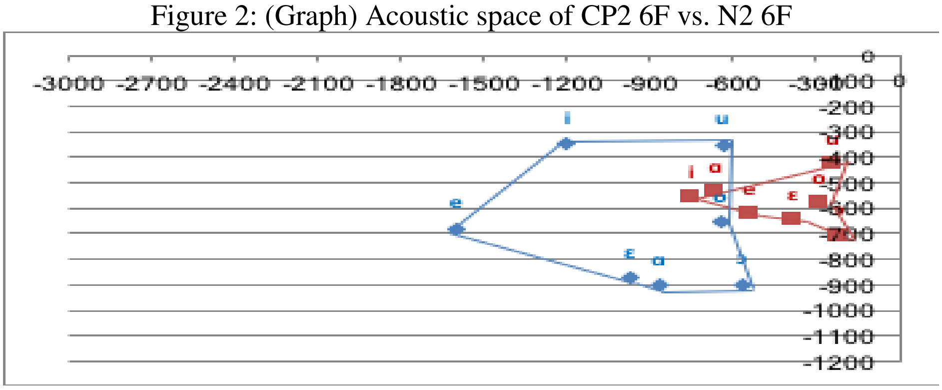
<u>CP2 6F vs. N2 6F</u>

In this section a comparison between the acoustic vowel space of CP2 6F and N2 6F has been made. CP2 6F is a six years old female cerebral palsy child and N2 6F is a neurologically normal six year old female child.

Table 5: Formant values of vowels of CP2 6F and N2 6F

Vowels	CP2 6F		N2 6F	
	- F1	- (F2-F1)	- F1	-(F2-F1)
i	-559.863	-752.446	-346.674	-1200.65
e	-622.792	-537.627	-678.556	-1596.33
ɛ	-647.473	-386.016	-873.352	-975.345
ɑ	-536.787	-660.26	-903.208	-866.434
ɔ	-708.331	-217.652	-897.704	-569.187
o	-581.988	-285.12	-652.455	-644.64
u	-429.5	-237.033	-350.363	-637.444

Figure 2: (Graph) Acoustic space of CP2 6F vs. N2 6F



5. DISCUSSION:

CP2 6F has the lowest F1 value as -429.5 Hz and highest as -708.331 Hz. For F2-F1 we find the lowest as -217.652 Hz and highest as -752.446 Hz. The range for F1 is 278.831 Hz and for F2-F1 the range is 534.794 Hz. N2 6F has the lowest F1 value as -346.674 Hz and highest as -903.208 Hz. For F2-F1 we find the lowest as -569.187 Hz and highest as -1596.33 Hz. The range for F1 is 680.087 Hz and for F2-F1 the range is 1681.105 Hz.

If we compare the acoustic space area used by the two participants, the area occupied by CP2 6F is 31974.186826 whereas N2 6F uses an area of 392263.954541. If we calculate the percentage we can say that the acoustic vowel space area of CP2 6F is 8.15% of N2 6F.

In the case of CP2 6F both the front back and high low distinction is not as well developed as compared to the normal child of the same age and gender. The back open unrounded vowel /ɑ/ occurs close to the front close unrounded vowel /i/ in case of CP2 6F. N2 6F has higher values of both –F1 and –(F2-F1) has compared to CP2 6F. The vowels occupy a much wider area in case of N2 6F with the front-back and high-low distiction well established. In case of CP2 6F vowels occupy a small acoustic area with little articulatory distiction amongst themselves.

6. CONCLUSION:

Due to the deficit of speech-motor control, children with cerebral palsy 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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