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Original Research Article

Articulatory Working Space Area in Children with Cerebral Palsy

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ABSTRACT

Background: The precision of the articulatory movement and the coordination of tongue and jaw movements in children with cerebral palsy may be analysed acoustically by constructing the vowel space area. Even though some studies on vowel space area among children with cerebral palsy have been carried out, most of these studies are hardly conclusive. Further, the studies focusing on Indian disordered population are a handful.
Aim of the study: The present study aimed at investigating the difference across formant frequencies and vowel working space area between individuals with cerebral palsy and age-matched control subjects.
Method: Two groups of subjects were recruited for the study. Group 1 comprised of 20 individuals with cerebral palsy and group 2 comprised of 20 age-matched neurologically intact individuals. Phonation samples of vowels /a/, /i/ and /u/ was recorded and formant frequencies were extracted. Further, the Vowel Triangle Area was also calculated.
Results: The results showed that there was a significant difference in formant frequency values between the subjects of group 1 and group 2. It was also noted that the vowel space area entailing vowels /a/, /i/ and /u/ of group 1 individuals was significantly reduced when compared to group 2. Thus, the results demonstrated more restricted tongue movements in subjects of group 1.
Conclusion: Further studies ought to focus on the correlation of the reduced vowel space area and the speech intelligibility measures to assist the therapy to improve speech intelligibility in individuals with cerebral palsy.

Key words: Vowel space area, Formant frequencies, Cerebral palsy.

INTRODUCTION

Cerebral palsy (CP) can be considered as the widespread aetiology of speech motor disorders among children. [1] CP is chiefly a disability of movement and posture in children. One of the definitions of CP was proposed by Mutch and colleagues [2] and the definition encompassed five chief pieces of evidences. CP is (a) an umbrella term; (b) is permanent but not unchanging; (c) involves a disorder of movement and/or posture and of motor function; (d) is due to a non-progressive interference, lesion, or abnormality; and (e) the interference, lesion, or abnormality is in the immature brain. An orthopaedic surgeon named William Little (1843) described the features of CP, and thus for some period, it was labelled as Little's disease. [3] Further, Osler (1889) named the word CP. [3] However, most of the definitions of CP commonly emphasizes that the CP is the result of a damage to developing brain that is non-progressive and results in impairment of speech, language and motor functions. As noted by Rosen & Dickinson (1992), the incidence of CP globally was 2-2.5 per1000 live birth. [4] Studies propose that 3 per 1000 children among developed countries are affected with CP. [5] In the United States of America, the research shows that CP subsists in about 3.6 per 1000 children. [6]

CP is a disorder of motor disturbance as a consequence of a non-progressive injury or an insult to the immature brain either before the birth of the child or in the early childhood. Not less than half the children with CP have associated problems such as Epilepsy, [7] various degrees of learning disability, [8] visuals deficits, [9,10] cognitive and sensory deficits [11] and behavioural problems. [12,13] Children with CP usually present with developmental delay, and/or speech and motor deficits. Disturbances in motor control of speech and language, with the impairments in cognition and proprioception, directly results in communication problems evidenced in children with CP. Impairments in speech, especially the articulation have received a huge focus compared to any other aspect of communication. Children with CP generally demonstrate dysarthria with changing severity. There are few documentations showing the articulatory incoordination between the lips, tongue, mandible, and velum in children with CP. [14]

Imprecise articulation is one of the major features of dysarthria [15] and, for children with severe speech disorders. Speech is affected in CP due to the underlying brain lesion and oromotor dysfunctions. Deficits in both receptive and expressive language skills are also frequent. Studies have also documented that about 38% of children with CP demonstrate impairments in articulation and speech. [16] Children with CP have impaired motor execution or articulation disorders as a result of the orofacial musculature impairments that avoid the accomplishment of the precise articulatory patterns necessary to produce speech sounds correctly. [17] Interestingly, defects of the orofacial musculature are generally assumed as the root cause for imprecise articulation in children with CP. [17]

Acoustic methods are valuable quantitative and accurate tools that assist in describing the existence and severity of motor speech disorders. Further, acoustic measures also aids in monitoring the progress in speech among persons with motor speech disorders. [18] Thus, as pointed out by Honda & Kusakawa, [19] the basis for utilizing acoustic measure to evaluate speech motor function is straightforward as the speech signal includes quantifiable acoustic measures those reflect on the characteristics of speech production and perception. Thus, the precision of the articulatory movement and the coordination of tongue and jaw movements in CP may be analysed through acoustic analysis and one of the acoustic methods that could be utilized for this purpose is the construction of the vowel space area using vowel formant frequencies.

Vowel space measures have been extensively employed in the area of research that investigates the aspects of articulation among various disorders, including dysarthria, [20] and to examine the intelligibility of speech. [21] The hypothesis underlying the use of this measure is that greater vowel working space reflects the better movement of the articulators with respect to tongue height (dimension of first formant frequency) or tongue advancement (dimension of second formant frequency). Thus, it is evident that intelligibility of speech is prejudiced in CP due to imprecise articulation that is characterized by a reduction in vowel space area. [22]

Several researchers have reported the compact vowel working space area in several speech disorders. McRae, Tjaden, & Schoonings [23] have reported a reduction in vowel working space area among adults with dysarthria. Further, researches have also reported similar findings among children with CP. [24,25] In general, a positive association between intelligibility of speech and vowel space area has been documented among individuals with motor speech disorders.

Thus from the literature review, it is clear that the formant frequencies vary in a reasonably predictable manner depending upon the articulatory movements and the vocal tract configuration and these changes could be predicted by constructing the vowel space area. Further, it is documented fact that children with CP have affected articulation due to which vowel space area can greatly vary. As motor speech disorders are mainly categorized by articulatory undershoot, i.e., restricted range of articulatory movements, the accurate movement of articulators and the degree of vocal tract closure are not completely accomplished. [26] Thus, considering vowel space area as a measure of the accurate articulation that indicate gross motor ability of the tongue and jaw coordination, the existing studies on vowel space area in the speech of children with CP are scanty. Even though some studies on vowel space area among individuals with childhood dysarthria have been carried out, most of these studies are hardly conclusive. Further, the studies focusing on Indian disordered population are a handful. Thus, the present study aimed at investigating difference across formant frequencies and vowel working space area between individuals with CP and age-matched control subjects.

MATERIALS AND METHODS

Participants

Two groups of subjects were recruited for the study. Group 1 consisted of individuals with CP. Group 1 included 20 individuals who were diagnosed with CP and were referred to the outpatient department of the JSS Hospital by a qualified neurologist and an occupational therapist. The talkers' ages ranged from 6 years to 12 years old and exhibited medical and speech therapy diagnosis as Flaccid CP. All the subjects of group 1 had normal hearing and visual ability, adequate intelligence, speech as their primary means of communication and Kannada as their first language based on the investigator's observation and the previous health-related records. The subjects having other associated problems such as mental retardation were excluded from the study. Group 2 consisted of 20 age-matched neurologically intact individuals. A convenience sampling strategy was used to recruit the subjects of group 2. All the subjects of group 2 were screened for their speech, language, hearing and cognitive skills. Further, the subjects who passed the screening were taken as the participants for the present study. Parent of each participant was asked whether they would allow their child to participate in the research study. The first twenty participants under each group who agreed to participate constituted the pool of participants. Each parent signed the informed consent form agreeing their child's participation in the study and to the dissemination of results.

Procedure

The recording took place in a room with relatively low ambient noise. Each subject was seated comfortably in a chair designed for individuals with CP in front of the laptop computer screen during the recording. Participants were instructed to sustain the phonation of vowel /a/ at their habitual pitch and comfortable loudness levels. Each individual was given several demonstrations of the task before the recordings. The voice recordings of participants were collected with a high-quality microphone onto the Praat software (version 5.3.23). The distance between the microphone and the participant's mouth was 15 cm. Recorded samples were digitized at a sampling frequency of 44.1 kHz and 16 bits/sample quantization.

Three trials of the phonation were obtained from each subject. Out of the three recordings, the most stable recording was chosen and the 5-second segment from the middle of the recording was taken for the further analysis. All the samples were analyzed in Praat software and formant frequencies were extracted from the samples. Further, the Vowel Triangle Area was also calculated for both the subjects of group1 and group2 using the formula given by Liu, Tsao & Kuhl. [24]

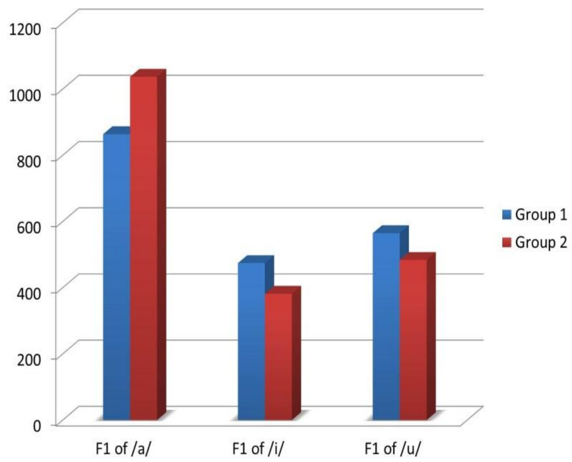
Statistical analysis: The tabulated data were subjected to both descriptive and inferential statistics using Statistical Package for the Social Sciences (SPSS 11.5; SPSS Inc, Chicago, IL). Mean and standard deviation values were obtained for the F1 and F2 of all the three vowels for the subjects of group 1 and group 2. As a part of inferential statistics, one-way analysis of variance (ANOVA) was carried out using an alpha level of 0.05 (95 % confidence interval), to see the effect of independent variable (groups) on every dependent variable (F1 and F2 of vowels /a/, /i/ and /u/ and vowel space area).

RESULTS AND DISCUSSION

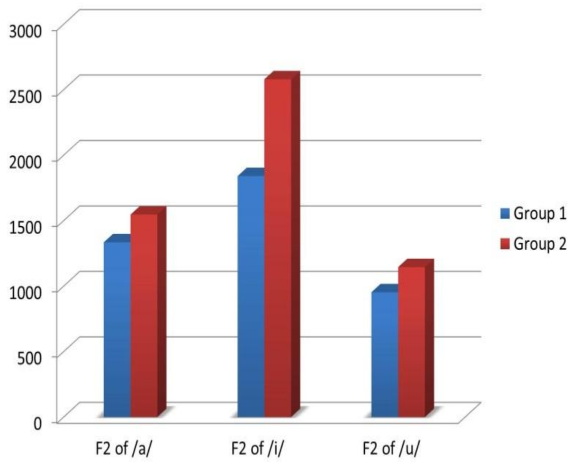
The present research intended to study the formant frequencies and to differentiate the vowel triangle area between the speech of children with CP and their age-matched controls. The results obtained from the acoustic analysis were treated with both the descriptive and inferential statistics. The table 1 shows the mean and standard deviation values of F1 and F2 acquired for all the three vowels for both the subjects of group 1 and group 2.

As it is evident from the graph 1 and table 1, across vowel /a/, group 1 subjects exhibited significantly lower F1 compared to that of group 2. On the other hand, the average F1 value of /i/ in group 1 was higher than that of group 2 and this difference was also significant. Similarly, the F1 of vowel /u/ in group 1 was higher than that of group 2 which also significant.

According to Peterson and Barney [27] & Hillenbrand et al, [28] variation in F1 is principally related to tongue height during vowel production. In the present study, it was noted that the F1 of the two high vowels /i/ and /u/ among group 1 speakers was significantly higher as compared to group 2 speakers. Thus the range of F1 values for the high-low vowel contrast reduces among group1 subjects (/i/ - /a/ = 389.5) as compared to subjects of group 2 (/i/- /a/ = 655.4). This constricted range of F1 values for the high-low vowel contrast implies that group 1 subjects have more restricted jaw and tongue vertical movements.



Graph 1: Depicting the mean values of F1 for all the three vowels in both the groups.



Graph 2: Depicting the mean values of F2 for all the three vowels in both the groups.

Table 1: Showing the results of one-way ANOVA for all three vowels performed between both the groups.

Source	F1 of /a/	F1 of /i/	F1 of /u/	F2 of /a/	F2 of /i/	F2 of /u/
F- value	6.407	5.245	4.863	9.808	22.405	7.143
Significance	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Across F2, as it can be observed from the graph 2 and table 1, it was interesting to note that F2 values across all the three vowels, i.e., /a/, /i/ and /u/ was significantly reduced in group 1 subjects as compared to group 2 subjects indicating the restriction in tongue advancement. F2 –F1 differences were also calculated for all the three vowels for the subjects of both the groups. In group 1 subjects, the high front vowel /i/ showed F2-F1 difference of 1366.18 Hz (i.e., F2/i/ - F1/i/ = 1840.47 Hz – 474.29Hz) and for high back vowel /u/ F2-F1 difference of 388.6Hz (i.e., F2/u/ - F1/u/ = 953.31 – 564.71) was noted. When compared to group 2, group 1 illustrated a significantly limited range of F2- F1 values for the front-back vowel contrast (/i/-/u/). It is a known fact that F2 or F2- F1 difference mostly varies with tongue advancement, i.e., the more anterior the tongue position, F2 and F2-F1 difference tends to be higher. Further, the limited range of F2-F1 reflects the reduced front-back movement of the tongue. Thus, the present study demonstrated more restricted tongue advancement in group 1 subjects.

The results of the vowel space area consisting of vowels /a/, /i/ and /u/ of group 1 individuals in support to formant frequencies exhibited significantly (t=3.660, $p<0.05$) limited vowel space areas when compared to group 2. The limited vowel working space area reflects the restricted movement of the tongue with respect to elevation and anterior-posterior movement for the group 1 individuals. Thus, the present study results are also in agreement with the result of the study carried out by Liu, Tsao & Kuhl. [24] They also studied the vowel working space area using both acoustic and perceptual approaches in twenty Mandarin-speaking young adults with CP in the age range of 17 to 22 years. The results showed significantly smaller vowel working space areas in the speech of adults with CP compared to ten age-matched controls. Even though the present study only considered children with CP, limited vowel working space area and centralized articulation were evidenced. Thus, the results reflected more restricted vertical and horizontal tongue movements in the speech of children with CP compared to their age-matched controls.

CONCLUSION

The present study aimed at documenting the differences among vowel space area between children with CP and normal speakers. A total of 20 individuals with CP and 20 normal individuals in the age range of 6 to 18 years participated in the study. Phonations of three vowels were recorded and analyzed using PRAAT software. The result of the present study showed that vowel space area in individuals with CP was much reduced than normals indicating the restricted and narrowed range of tongue and jaw movements. However, in the present study, the vowel space area was analysed with respect to a specific subcategories of CP i.e., the flaccid type of CP. The study failed to comment on the gender-linked differences across the measures of vowel space area. Nevertheless, from a clinical point of view, the study approves that the measure is a reliable and powerful marker of tongue movement and articulatory coordination among individuals with CP. Further studies ought to focus on the correlation of the reduced vowel space area and the speech intelligibility measures to assist the therapy to improve speech intelligibility in individuals with CP.

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