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Research Article

Acoustic Vowel Space in Children and Adults with Stuttering

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ABSTRACT

The aim of the study was to investigate the acoustic vowel space area in fluent segments of speech of children and adults with stuttering. An attempt was also made to explore the influence of intervention and phonetic context on the vowel space area. A total of 31 native Kannada speaking participants were included in the study. The group with stuttering included 7 untreated adults, 7 treated adults and 5 treated children. The typical group comprised of 5 children and 7 adults. The stimuli consisted of nine non-words in CVCV combinations which were attached with a carrier phrase. Non-word CVCV combination consisted of three corner vowels (/a/, /i/, /u/) in three phonetic contexts (/p/, /t/, /k/). F1 and F2 were measured using PRAAT software and the values were plotted in the MATLAB software to calculate vowel space area. The results revealed a significant difference between untreated and typical adults and between treated and untreated adults. It can be concluded that persons with stuttering exhibited restricted articulatory movements since there was a reduction in vowel space, which was not seen post treatment.

Keywords: Acoustic vowel space; Oral cavities; Pharyngeal; Voice spectrum

INTRODUCTION

Speech which comprises of vowels and consonants is considered as a physical event and the acoustic signal is the end product of speech. Vowels are produced with a relatively open vocal tract with no significant constriction of the oral (and pharyngeal) cavities. The production of vowels creates oropharyngeal resonating cavities which amplify certain frequency bands of the voice spectrum. These harmonics (formants), define the single vowels by their typical distinct peaks of acoustic energy. Vowel formant frequencies are among the most frequently reported acoustic measures of speech.

The first two formants are important in determining the quality of vowels and are frequently said to correspond to the position of the tongue. F1 frequency is inversely related to the height of the tongue whereas the F2 frequency is directly related to the frontness of the tongue.

More recent work exploring the relationship between the acoustic dimensions and tongue kinematics provided further evidence that F1 reflects a relatively good approximation of tongue height (and openness of the vocal tract), whereas F2 reflects the tongue variations in both dimensions, height and advancement.

Formant frequencies are crucial in assessing intelligibility and naturalness of speech [1].

Corner vowels have received special consideration as they represent the periphery of the vowel system. There is mainly three corner vowels /a/, /i/, and /u/ is a low mid unrounded vowel, /i/ is a close front high vowel and /u/ is a close back high rounded vowel.

These vowels are important phonemes in speech, as they are found in most human languages and outline the acoustic and articulatory space of all vowels.

When the F1 and F2 of the corner vowels are plotted graphically with F1 on Y-axis and F2 on X-axis, it takes the shape of a quadrilateral (four vowel plot) or triangle (three vowel plot). This triangular size gives the vowel articulatory working space.

This vowel articulatory working space, also called as acoustic vowel space varies with age, gender, language, dialects and phonetics context of the vowel (Figure 1).

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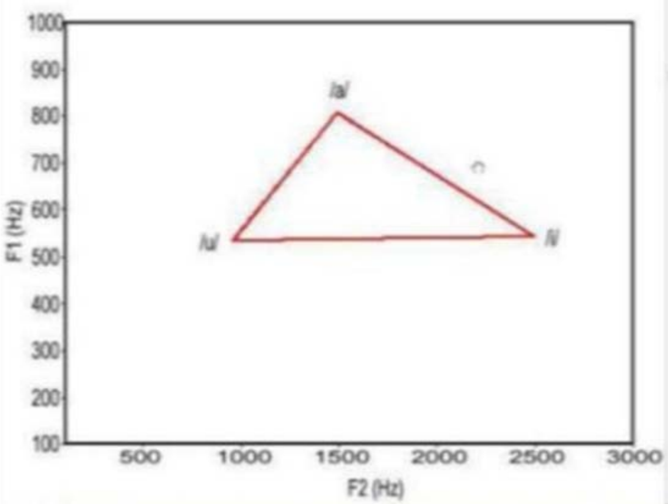

Figure1: A vowel triangle.

Since frequencies of the first and second formants roughly relate to the size and shape of the oral cavity and the position of the articulator, studies have investigated this aspect in the typical and atypical speakers. Studies have shown that shown that the acoustic vowel space is larger in speech that is clearer and more intelligible. This is interpreted as corresponding to greater articulatory excursions and more distinct acoustic-articulatory vowel targets.

Acoustic vowel space has been investigated in individuals with stuttering as well. Stuttering is a disorder of fluency where communication difficulties are the central component because of a disruption in fluency. Van Riper defined "stuttering as a temporal disruption of a simultaneous and successive programming of muscular movements required to produce speech sounds or its link to the next sound". Based on spectrographic and cineflurographic analysis, he suggested that during repetitions, highly inappropriate articulatory postures may be used, both in voiced and unvoiced sounds. The disruption is characterized by repetitions, hesitations, prolongations and audible pauses [2].

Klich and May found that the F1 and F2 values in the fluent CVC productions were more centralized in adults with stuttering compared to those with no stuttering. The obtained formant frequencies of various vowels fell short of the idealized target values for that vowel, resulting in an overall shrinkage of vowel space. They suggested that the persons with stuttering produced vowels using a neutral vocal tract posture as a means of controlling speech fluency. This is supported by Zimmermann who found reduced amplitude of tongue movement in the fluent speech of adults who stutter.

Compared the formant frequencies of fluent and disfluent vowels of adults with stuttering and the formant frequencies of fluent vowels of adults with and without stuttering in an F1-F2 vowel space and in a normalized F1-F2 vowel space. The results indicated that there were differences in formant frequencies between the vowels of persons with and without stuttering which was attributed to the vocal tract dimensions. They also found no differences between the formant frequencies of the fluent and disfluent vowels produced by persons with stuttering. They concluded that persons with stuttering do not exhibit significantly greater vowel centralization than the persons with no stuttering.

Investigated the vocal tract vowel space in three different ways during fluently produced utterances through examination of the first two formant frequencies in untreated and treated adults with stuttering and nonstuttering adults. The steady-state portion of formant one (F1) and formant two (F2) was examined in the production of various CVC tokens containing the vowels /i/, /u/, and /a/. They found that the formant frequency spacing measure amongst the three ways, best differentiated the two groups. The vowel space area was found to be lesser for untreated adults with stuttering when compared to treated adults and control group. These differences were attributed to articulatory undershoot in individuals with stuttering. They reported that the untreated stutterers had a tendency to use a neutral vocal tract posture during fluent productions [3].

Altering the speaking rate, which is inherent in fluency intervention programs could also influence the vowel space area. Hirsch found that at a normal speaking rate, vowel space reduction was seen in non-treated French speaking persons with stuttering. However, when the speech rate increased, there was no reduction seen in vowel space in them. In the treated persons with stuttering and control speakers, there was no reduction seen in vowel space at the normal speaking rate, but when speech rate increased reduction was seen.

A systematic review of the available literature revealed that studies pertaining to the investigation of vowel space in persons with stuttering are limited. Most of the existing studies have focused on adults with stuttering. In children with stuttering, such studies are scarce. Most of the acoustic studies carried out in persons with stuttering have investigated the vowel duration, F2 transition etc., which seem to imply that abnormal vocal tract adjustments occur only during formant transitions, whereas the vocal tract posture related to the steady-state portion is essentially normal. However, it is premature to draw such conclusions since studies investigating this aspect is less prevalent [4].

Further, the studies evaluating the influence of intervention techniques on the vowel space in persons with stuttering are scanty. The techniques used in the intervention of persons with stuttering could possibly have an influence on the vowel space, as the intervention may involve the modification of rate. Evaluating the vowel space area may reveal articulatory subtleties associated with maintaining fluency and may assist in the establishment of more appropriate treatment techniques. Thus, it would be interesting to study the acoustic vowel space in treated and untreated persons with stuttering in comparison with the persons with no stuttering.

Since phonemes are rarely produced in isolation, but rather in the context of phoneme sequences, the investigation of influence of different phonetic contexts on acoustic vowel space was also planned as a part of this study. Such studies, particularly in the speech of persons with stuttering are limited. There is a need for such studies in different languages as well, since formant durations and acoustic vowel space vary with language and dialect. Since such studies in the Indian scenario are limited, this study was planned with the aim of investigating the acoustic vowel space in persons with stuttering [5].

MATERIALS AND METHODOLOGY

A total of 31 participants were included in the study. The clinical group comprised of 7 untreated adult males with stuttering, 7 treated adult males in the age range of 18-25 years, and 5 treated children with stuttering in the age range of 5-10 years. The control group consisted of 5 age matched typically developing children and 7 typical adult maleswith no stuttering. All the participants were native speakers of Kannada. They were very proficient in speaking and understanding Kannada and had an exposure to English too. They all had a working knowledge of English. The International Second Language Proficiency Ratings scale developed by (Ingram, 1985) was used to check the language proficiency in the second language English. ISLPR describes language performance at eight points along the continuum from zero to native like proficiency in each of the four macro skills (speaking, listening, reading and writing). The scale is divided into primary (speaking and listening) and secondary skills (reading and writing). It has 8 ratings which includes 0, 0+, 1, +1, 2, 3, 4, 5 as rated from a continuum zero proficiency to native like proficiency. The participants obtained a rating of '2' and were equally proficient in listening, speaking, reading and writing in English language.

Further, there was no history of hearing, language, cognitive, academic, emotional, and neurological disorders in any of the participant and there were no structural or functional or facial deficits. They were also matched for their socioeconomic status using the NIMH socioeconomic status scale. The scale has sections such as occupation and education of the parents, annual family income, property, and per capita income to assess the socioeconomic status of the participants. Interpretation on this scale showed a middle socioeconomic status for all the participants [6].

The participants in the clinical group were diagnosed as stuttering by qualified Speech-Language Pathologists. This was estimated by marking their speech sample obtained through a conversation for disfluencies and measuring the percentage of disfluencies from the total words in the sample. The severity was calculated using SSI-3based on frequency (included job task and reading task), duration of disfluencies (duration of three longest blocks) and physical concomitants exhibited by these adults. Based on the results from the SSI, all the adults considered in the groups exhibited moderate stuttering. The participants in the stuttering group had undergone the fluency intervention program and had attended an average of 15-20 sessions for a minimum duration of 40 minutes per day to improve fluency. The prolongation technique was specifically used as a technique to minimize the disfluencies. Ethical procedures were used to select the participants, that is, the participants were explained the purpose and the procedures of the study and an informed verbal consent were obtained.

The participants were seated comfortably in the recording room one at a time with as minimal noise and distractions as possible. A small general conversation was carried out initially to make the client comfortable and familiar with the examiner, the settings and the task. Instructions specific to the task were given in Kannada. Sentences were presented in a random order and each stimulus was presented four times, so that the participant had to read a total of 36 sentences. Recording was done using an Olympus WS-550M Digital Voice Recorder in a sound proof room [7].

Analysis of data was done using PRAAT software and a MATLAB based program. PRAAT was used to find the formants F1and F2 from the target vowel and average of F1 and F2 was taken for three target vowels in three different contexts /p/, /t/, /k/. Thus 6 values in each context (3 values for F1 and 3 values for F2) and a total of 18 values were obtained per participant.

For the acoustic analysis using PRAAT, the recorded samples were transferred to a personal computer with features of stereo channels, 16 bits, Microsoft PCM format, wav output type, with a sampling frequency of 44100Hz. Target words were extracted from the carrier phrase and F1 and F2 were calculated from midpoint of each target vowel in a spectrum. The average was calculated from four trials for each vowel for each phonetic context which were recorded in different combinations [8].

The average value of the formant frequencies was entered in MATLAB based program and the vowel triangle and vowel space area was calculated. Eighteen values were entered to the program (6 per triangle) to get 3 vowel triangles for 3 phonetic contexts /p/, /t/ and /k/. These three triangles were obtained together in order to compare the vowel space area in three different phonetic contexts. Three different colors were assigned for the triangles for the easy comparison as depicted.

This data was fed to the computer for statistical analysis using SPSS software, version 21. Descriptive statistics was used to compute the mean and the standard deviation. The results of Shapiro wilk test of normality revealed that data pertaining to treated and untreated persons with stuttering were not normally distributed ($p<0.05$). Hence non-parametric tests such as Mann Whitney U and Friedman test were performed for statistical comparison of the data [9].

Objectives

To compare the vowel space area between the untreated and treated adults with stuttering.

- To compare the vowel space area of the untreated and treated adults with stuttering with the typical adult group.
- To compare vowel space area between treated children with stuttering and typically developing children.
- To explore the influence of three phonetic contexts (/p/, /t/ and /k/) on the vowel space in all the groups.

RESULTS

It was found that the mean values of vowel space area showed an observable difference across all the groups and different phonetic contexts. The mean and the standard deviation (SD) in untreated and treated adults with stuttering and those with no stuttering in all three phonetic contexts have been depicted. The mean vowel space area was the lowest for the untreated adult group with stuttering in comparison to the typical and the treated group in all the phonetic contexts. The mean vowel space area was lower for the treated adults than the typical adults only for the /t/ and /k/ context [10].

The mean and the Standard Deviation (SD) in untreated children with stuttering and those with no stuttering in all three phonetic contexts have been depicted. The mean vowel space area was lesser for the treated group of children than the typical group of children for all the phonetic contexts (Table 1).

PhoneticContext	Group	Mean	SD
/p/	Typical Children	431.96	77.89
	Treated Children	378.27	85.30
/t/	Typical Children	389.02	33.72
	Treated Children	328.94	59.00
/k/	Typical Children	353.32	47.21
	Treated Children	297.55	73.74

Table 1: Mean and Standard Deviation (SD) of vowel space area in treated children with stuttering and those with no stuttering in all three phonetic contexts.

Kruskal Wallis test was done to compare the vowel space area across treated group of persons with stuttering, untreated group of persons with stuttering and typical adults across all three phonetic contexts. The results revealed a significant difference across all the three adult groups across all the three phonetic contexts [11].

The Mann Whitney test was carried out for between group comparison of vowel space area of the treated and untreated adults with stuttering with the typical adult group. The results revealed that there was no significant difference between the typical group and treated persons with stuttering. However, there was a high significant difference between untreated persons with stuttering and the typical adult group across all the three contexts (Table 2).

Phonetic Context	**Adult Group**	**/z/ value**	**P value**
/p/ context	Untreated	2.88	0.004*
	Typical		
/t/ context	Untreated	3.13	0.002*
	Typical		
/k/ context	Untreated	2.88	0.004*
	Typical		
*P<0.01			

Table 2: Results of the Mann Whitney test between the untreated and the typical adult group.

The Mann Whitney test was also carried out for the comparison of vowel space area of the treated adults with stuttering with untreated adults with stuttering. The results revealed a significant difference between untreated and treated adults with stuttering (Table 3) [12].

PhoneticContext	**Groups**	**/z/**	**P value**
/p/ context	Untreated	3.13	0.002*
	Treated		
/t/ context	Untreated	3	0.003*
	Treated		
/k/ context	Untreated	2.74	0.006*
	Treated		
*P<0.01			

Table 3: Results of the Mann Whitney test between the untreated and the treated adult group.

The results of the Mann Whitney test to compare the typically developing children and treated children with stuttering revealed that there was no significant difference between these two groups.

Further it was seen that in the typical and untreated adults, the mean vowel space area was highest for the /k/ context, whereas for treated adults with stuttering, the mean value was highest for the /p/ context. In both the groups of children the mean was highest for the /p/ context and least for the /k/ context. To investigate the influence of phonetic contexts (/p/, /t/ and /k/) on the vowel space in the adult and children groups, Friedmann test was performed. The test results revealed that there was no significant difference in vowel space area among all the phonetic contexts in all three adult groups. However, in children there was a significant difference across all phonetic contexts only in treated group ($\chi 2$ =7.60, p =0.02).

DISCUSSION

The results of the study showed that there was a significant difference in vowel space area between untreated adults with stuttering and the typical group and between treated and untreated adults with stuttering, with the participants in the untreated group showing a reduction of vowel space area. It was also found that there was no significant difference between treated persons with stuttering and the typical adult group. These results indicated that the treated persons were moving their articulators appropriately during the speech production, whereas the untreated persons with stuttering had restricted movement of articulators. The participants in the treated group had attended the fluency intervention program and were fluent which could have led to the significant difference between the treated group of adults and the untreated group. Also reported that persons with stuttering had a tendency to maintain a more neutral vocal tract posture than non-stuttering individuals with restricted movement patterns of the articulators.

Further the present study revealed that there was no significant difference in the vowel space area between typically developing children and treated children with stuttering. This again could be attributed to the fluency intervention program undertaken by the children. Though there was no significant difference, the mean vowel space area was slightly lower for the treated group than the typical group, indicating some restriction in the articulators. However, the vowel space area could not be assessed in an untreated group of children with stuttering, which could have added provided an insight into the articulatory dynamics. These findings obtained in treated adults and children with stuttering imply that the prolongation technique implemented as a part of fluency intervention program, had an influence on the articulatory dynamics. This could be because of the fact that when speech rate is reduced, it provides more time for the articulators to reach their target position [13].

The present study revealed a significant difference across all phonetic contexts only in treated children with stuttering. The mean values were found be highest for the /p/ context and lowest for the /k/ context in typically developing children, treated children with stuttering and treated adults with stuttering. This finding has an implication in fluency intervention. Words with /p/ context can be used more often to optimize the articulatory movement, particularly in children. Krishnan, found similar results in the typical children which is explained by the developmental acquisition of the sounds, ease of production of vowels and movement of tongue. For /p/ context tongue has maximum degree of freedom and it is easy to produce and is a sound that develops much earlier in life. Hence for /p/ context, the vowel space area is more. While /t/ and /k/, being retroflex and velar respectively, has limited degree of freedom of tongue movements which accounts for smaller vowel space. However, the native spoken language of the participants in both the studies was different and one has to exercise caution before generalizing the results of the study. Seven and House also reported an effect of place of articulation of consonants on the formant frequencies. Further studies with a larger sample size may help to draw conclusive findings.

In the present study, no significant differences were found across contexts in the adult groups. However, the typical adult group and untreated persons with stuttering obtained high mean values of vowel space area in the /k/ context and the treated group obtained high mean vowel space area for the /p/ context. This finding was also in agreement with the where similar findings were seen in the adult group. This can be explained through the manner of production of these sounds. The coarticulatory effects were more for /k/ than /p/ and /t/, thereby increasing F1 and reducing F2 resulting in the stretching of vowel triangle from the optimum position, thus resulting in a larger vowel space area [14].

CONCLUSIONS

The present study attempted to investigate vowel space area in children and adults with stuttering. The study also attempted to assess the influence of intervention on the vowel space area in both the groups. It also aimed to find the influence of phonetic context (/p/, /t/ and /k/) on the vowel space area in all the groups. The results revealed a significant difference between untreated adults and typical group, between treated adults and untreated adults, and between typical adult group and the typical pediatric group. It can be concluded from the study that persons with stuttering, especially post treatment, did not exhibit restricted articulatory movements since there was no reduction in vowel space but prior to treatment, they did exhibit restricted articulatory movements as reflected through the reduction in vowel space. This study provides additional data concerning the steady-state formant frequency characteristics of fluent vowel productions in individuals who stutter. However, there are some limitations of the study. An attempt was not made to document the speaking rate, which could have had an influence on the vowel space area. The sample size in each group considered in the study is limited, with no inclusion of untreated children with stuttering. Future studies can be carried out by increasing sample size and the groups. Studies can be also carried out to investigate the influence of severity of stuttering and varied intervention techniques, both in children and adults.

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