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Acoustic Analysis of Vowels in Kashmiri-Speaking Adolescents with Down Syndrome

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Abstract
The study examined the acoustic characteristics of four corner vowels /i, a, ɔ, u/ in CVC contexts produced by Kashmiri adolescent speakers with Down syndrome. The acoustic variables that were investigated include First formant (F1), Formant second (F2), and Vowel space area. Participants were ten Down syndrome adolescents in the age range of 13 to 18 years, and ten age and gender-matched controls. The results showed significant variability in F2 parameter for vowels /i/, /a/ and /ɔ/ and no difference in /u/ vowel was found between Down syndrome and Control group. The study also found no significant differences in F1 parameter of all the four vowels between the two groups. The smaller Vowel space area based on mean formant (F1& F2) values was also observed in Down syndrome.
Keywords: Down Syndrome, Acoustic Analysis, Formants, Vowel Space

INTRODUCTION

Down syndrome, also known as Trisomy 21, is one of the most identified genetic conditions and the most prevalent disorder caused by the chromosomal anomaly. It is also the most commonly understood cause of intellectual disability (Katz et al., 2008). Down syndrome persons are often found to have problems in their speech. The speech of individuals with Down syndrome is marked by the presence of segmental errors-vocalic and consonantal (Bunton et al., 2007; Van Borsel, 1996) and aberrations in acoustic characteristics (O'Leary, 2020). Some of the studies focusing on the articulatory aspect of speech produced by Down syndrome (DS) have discussed the impact of impaired speech on the overall phonological development in such Individuals. Sutherland & Gillon (2007) found that impairments in speech result in the poorly developed phonological system and has direct effects on the listening and speaking abilities of people with Down syndrome. Barnes et al. (2009) observed that Down syndrome boys had less phonological awareness and were able to produce less intelligible words, often resulting from impairment in their speech.

The impairment in speech are usually attributed to anatomical features (such as midface hypoplasia), and physiological features (hypotonia of the lips and tongue) and that one or both of these factors are commonly associated with low articulatory movements,

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thereby, resulting in reduced speech intelligibility in Down syndrome (Miller and Leddy, 1998). In Down syndrome, the ability to produce consonants of a language appears similar to that of typical individuals, but these people often report difficulty in the correct pronunciation of a word (Stoel-Gammon, 1980). Other studies have also reported errors in the production of vowels based on their articulatory parameters suggesting a delay in the overall phonological development of such Individuals (Van Borsel, 1996). In addition, people with Down syndrome do not only exhibit problems in the articulation of certain sounds but also show an atypical pattern of speech at suprasegmental level, as is found in their voice quality (Moura, 2008).

The formants F1 and F2 are the fundamental acoustics correlates of vowel quality or Identity, Where F1 refers to vowel or tongue height, and F2 is associated with vowel frontness or backness or, in other words, it relates to the anterior-posterior position of the tongue (Ladefoged, 1996). Data from studies on patients with speech problems have proposed a link between Vowel formants and speech intelligibility (Weismer et al., 2001; Higgins & Hodge, 2002).

Vowel space or vowel limit is the fixed space within the oral-pharyngeal cavity; thus, the vowel of any language must have its tongue-position either on the vowel limit itself or within the vowel space (Catford, 1998). Therefore, acoustic vowel space involves plotting of vowels in the corners of a vowel quadrilateral on an F1, F2 axis. Sometimes, the corner vowels can also take the form of a triangle depending upon the language being discussed (Skandera & Burleigh, 2005). Several studies have adopted this measure to identify the acoustic correlates of a disordered speech (Weismer et al., 2001; Higgins & Hodge, 2002). Carl (2018), in an ultrasound study, reported variability in acoustic data between Down syndrome and the Control group and found a decrease in vowel space for low vowels in the speech of Down syndrome persons. (Skandera & Burleigh, 2005)

Acoustic characteristics have been studied but not widely in persons with Down syndrome, and almost all of this research has focused on English, French and German. To our knowledge, no previous study had attempted to identify the acoustic characteristics of vowels of Kashmiri in the speech of Down syndrome Individuals. The study was conducted to compare and analyze the acoustic parameters of F1 and F2 and to construct a vowel space area between Kashmiri speakers with Down syndrome and normal adolescents (Control group). The vowels that were selected for the present study are /i/, /a/, /ɔ/ and /u/ and form the four corner vowels of Kashmiri Vowel quadrilateral or area (koul, 2005). Evidences from the acoustic analysis of vowels was presented, and factors including vowel formant frequencies (F1, F2) and vowel space were examined, and differences as a result of the syndrome were identified and discussed.

METHOD

Participants

Ten adolescents with Down syndrome (Trisomy 21), 5 males and 5 females in the age range of 13-18 years were included. All the Down syndrome individuals that were selected for the present study had no previous history of hearing impairments and were having obstructions in their speech. The Down syndrome participants were selected from

various rehabilitation Institutions of Kashmir, India. In Control group, ten adolescents matched for age and gender were selected. The individuals in the Control group had no records of language, speech, or hearing problems. All the Down syndrome and normal control adolescents were native Kashmiri speakers.

Data Collection

The Acoustic data were recorded in a soundproof room, using an external voice recording device (Sony, ICD- UX560F) and an external sound Mic with stand (Com-Tech, NET KTV). The microphone was placed at a distance of ~14 cms away from the respondent's mouth. The stimuli comprising monosyllabic words were presented in a Consonant-vowel-Consonant (CVC) format, where Vowel = / i,a,ɔ,u / and consonant = / k, g,m,n,t^h, r,d, /. The participants were asked to repeat each syllable at an average loudness and pitch levels and as per their usual ways of speaking.

The mean formant frequency (F1& F2) values of the recorded syllables were determined with the help of PRAAT version 6.1.09 (Boersma & Weenink, 2002) and were manually inspected and tabulated on separate Excel sheets. The extraction of a vowel from each recorded voice sample was carried through observation of Wide-band Spectrogram and amplitude-by-time supplemented by perceptual Judgment (Whitehall et al., 2006). The script consisting of F1& F2 mean values for each of the four Kashmiri vowels produced by each speaker was used for statistical analysis to investigate significant differences between Down syndrome and the Control group.

Statistical analysis

The statistical significance for each vowel between Down syndrome and the Control group was carried out on F1 and F2 parameters. The difference between the two group means was determined by using the student's unpaired *t*-test. The significance was calculated at the $p < 0.05$ level of significance (Snedecor & Cochran, 1967).

The results are shown in bar graphs/figures. The comparative height of the bars on a particular vowel indicates the comparative value of the parameter for the two groups on that vowel. The numeric value of the parameter can be calculated from the graphs by marking the point at which a straight line drawn from the maximum height of the bar intercepts the vertical or Y-axis (parameter axis).

RESULTS

Formant First (F1)

The results of the difference between Down Syndrome and Control group using Student's unpaired t-test for vowels /i/, /a/, /ɔ/ and /u/ on the acoustic variable of F1 are presented in Figure 1. As the formant (F1) relates to the height of the tongue in the production of a vowel (Kent et al., 1992), we found that F1 mean value of Down syndrome group for vowel /i/ was low and non-significantly different from the Control group ($p>0.05$). Similarly, the comparisons between Down syndrome and Controls on the F1 parameter for all the other vowels /a/, /ɔ/ and /u/ also revealed non-significant differences ($p>0.05$).

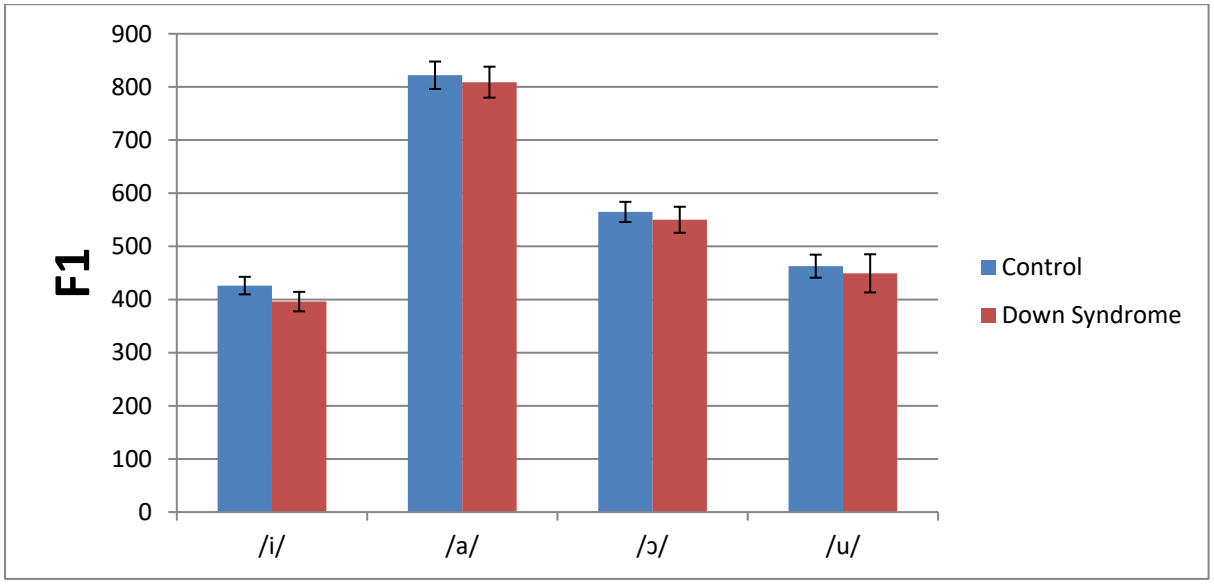

Figure 1. Difference in F1 frequency between Down syndrome and the Control group. Results represent mean ± SEM. F1: Formant First.

Formant Second (F2)

Figure 2 presents the results for the difference in the acoustic variable of F2 frequency of vowels (/i/, /a/, /ɔ/ and /u/) produced by the speakers of Down syndrome and Control group. The F2 acoustic variable corresponds to the front-back position of the tongue (Kent et al., 1992), it was found that the difference in mean F2 values for vowel /i/ between Down syndrome and Control group was statistically significant ($p<0.05$). There was no significant difference in F2 values between the two groups for vowels /u/ ($p>0.05$). However, the mean F2 values of vowel /a/ indicated a significant difference ($p< 0.05$) between the two groups. Similarly, for Vowel /ɔ/ difference in F2 mean was also found to be significantly higher ($p< 0.05$) in Down syndrome than its respective Control group.

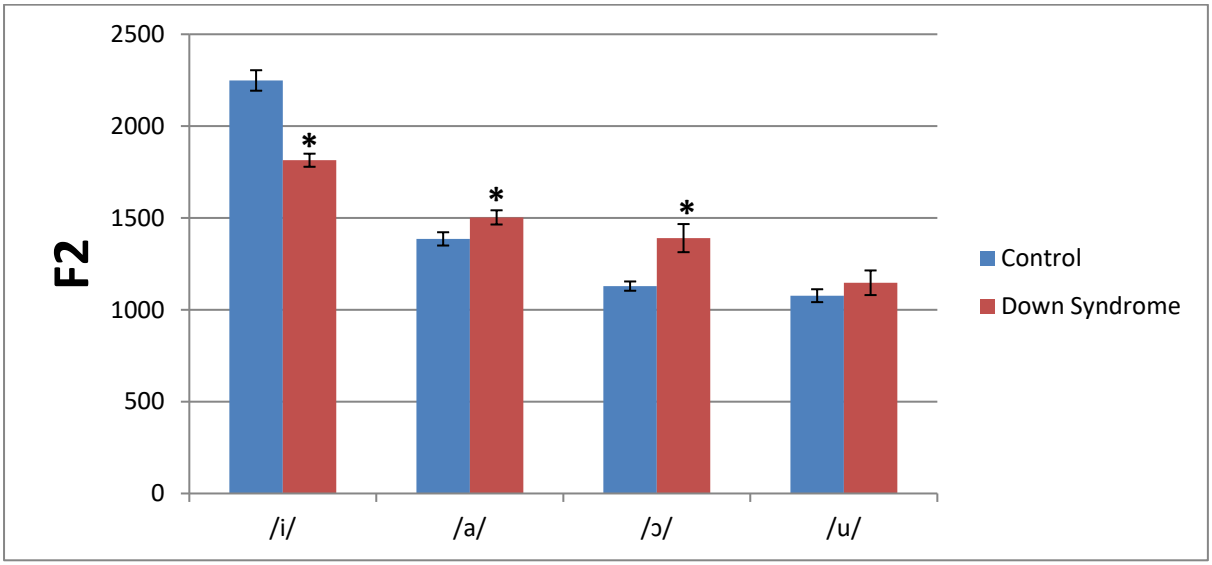

Figure 2. Difference in F2 frequency between Down syndrome and Control group. Results represent mean ± SEM. Bar on a particular vowel with superscript (*) differ significantly from its respective Control group at $p < 0.05$. F2: Formant Second.

Vowel space area

Vowel space refers to the area covered by four corner vowels of a language in an F1 and F2 axis. Catford (1988) maintains that the idea of cardinal vowels, as proposed by Daniel Jones, is based on the concept that the vowels are limited by vowel space. He reports that the production of a vowel takes place in a certain fixed space or area within the oral-pharyngeal cavity, and beyond this space, the vowel produced becomes similar to an approximate type of sound. In Kashmiri, the four corner vowels that represent the vowel area are /i/, /a/, /ɔ/ and /u/ (Koul, 2005). A vowel area was formed based on the mean values of the First and Second Formant of these vowels from Down syndrome and Control group and were plotted on an F1 vs. F2 graph (Figure 3). Evidence of reduced Vowel space in Down syndrome can be seen in both the F1 and F2 space (Figure 3).

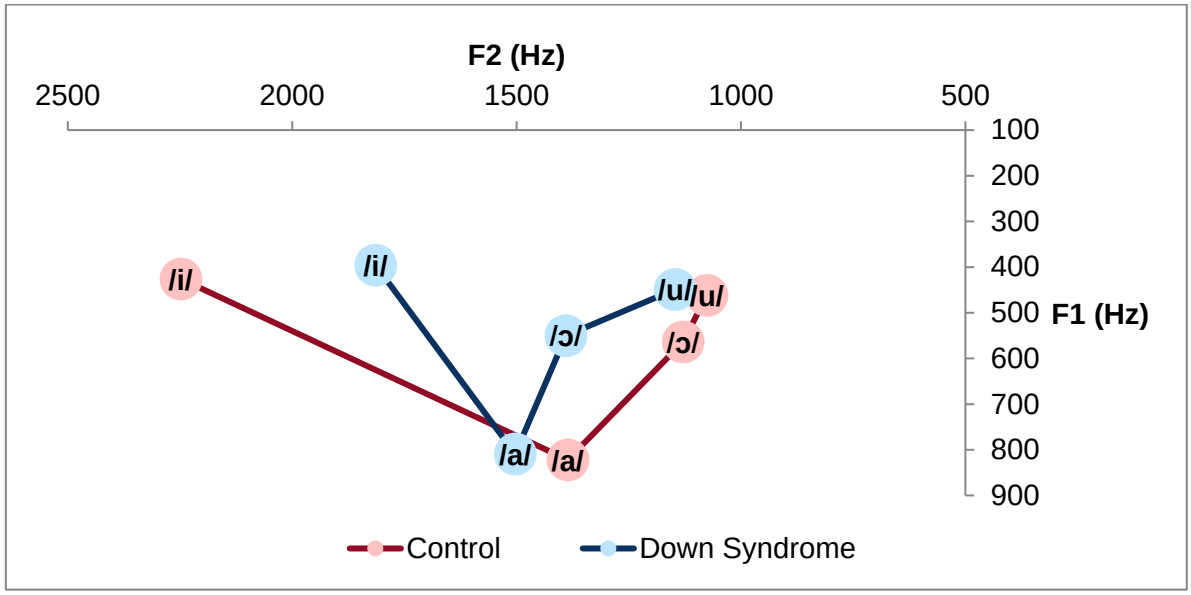

Figure 3. Mean acoustic space in Hertz for Down syndrome and Controls is shown. Different vowel notations have been used to identify and compare the Vowel space areas.

DISCUSSION

The purpose of the study was to analyze the acoustic measures F1 & F2 of four Kashmiri corner vowels produced by Down syndrome adolescents. Our findings report no statistically significant differences in mean F1 values between the Down syndrome and Controls (Abolhasanizadeh et al., 2018). This suggests that the speakers with Down syndrome are more or less able to produce lingual height similar to their Controls during the production of high and low vowels. However, it requires further research to explore this phenomenon.

The significant difference in F2 frequency for low vowels /a/ and /ɔ/ are consistent with other findings (Carl et al., 2020). We found that the F2 frequency of / a/ and /ɔ/ vowel is comparatively higher, and the vowels are produced more towards the center (Figure 3) from their original position. Our results are also consistent with the findings which report of reduced F2 frequency for vowel /i/ (Fourakis, 2010). The vowel /i/ is produced when the tongue makes extreme advancements on the anterior-posterior dimension. Therefore, reduced F2 of this vowel may be related to the limited movement of the tongue

during its production. Studies have also reported reduced differentiation between tongue shapes of all the four corner vowels in Down syndrome (Carl, 2018). F2 range has a greater correlation with vowel intelligibility (Whitehill, 2006). Therefore, the F2 range plays a significant role in determining the vowel intelligibility of the speakers with Down syndrome.

Several investigations on the vowel space area have reported contradictory findings**.** Petska et al. (2014) found that acoustic vowel space in adults and children with Down syndrome is comparatively smaller than that of a normal group. Similarly, a study by Bunton and Leddy (2011) also noted a shortened vowel space in Down syndrome adults. In contrast, Rochet-Capellan and Dohen's (2015) study on the acoustic characterization of vowel production by young French adults with Down syndrome proposed for a larger vowel space area than their Control group. However, our results have observed a compressed vowel space area (Figure 3) for Kashmiri speakers with Down syndrome and are in line with the previous studies supporting a smaller vowel space area.

CONCLUSION

In summary, the findings of our study reported the results of acoustic analysis of F1 & F2 parameters of four corner vowels produced by Kashmiri-speaking adolescents with Down syndrome. We found that there is an atypical production of vowels, and our findings corroborate the previous works, which have found differences in the F2 range for both high front, and low front and back vowels in speakers with Down syndrome. However, no statistically significant differences were found for F1 formant. Furthermore, the study also presented a reduced Vowel space area in Down syndrome adolescents than their Controls.

People with Down syndrome are often characterized by having impairment in their speech. Understanding the nature of Speech deficits in such individuals has received much scientific attention, but the acoustic properties of their speech have not been widely delineated. It has been found that people who exhibit problems in speech are more likely to develop problems in their ability to learn to read. The impairment in the speech of such people can hamper effective communication. Therefore, it is important to provide a more detailed investigation of speech acoustics and articulatory parameters in order to formulate effective plans that can be adapted to provide necessary speech interventions.

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