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A Developmental Study of Vowel Acoustics in Individuals with Down Syndrome

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INTRODUCTION

Down syndrome (DS), the most common genetic disorder, is caused by the presence of an extra copy of chromosome 21. About 1 in 700 infants are born with Down syndrome or trisomy 21. Speech difficulties affecting speech intelligibility or speech clarity are common in individuals with DS. For a recent review of disorders of voice, speech sounds, fluency and intelligibility in DS, see Kent and Vorperian[1].

Acoustic studies may help to understand the reduced intelligibility in DS and to shed light on anatomic and motor factors contributing to the speech disorder. This study focuses on the area of the vowel quadrilateral in the F1-F2 plane. Reductions of quadrilateral area have been linked to reduced intelligibility in certain speech disorders.

The **purpose** of this study is to compare the vowel acoustic spaces of speakers with DS and speakers who are healthy and typically developing (TD). Vowels spaces are analyzed as graphic displays of the F1-F2 vowel quadrilaterals for individual participants. In addition, data are reported for two measures: Vowel Articulation Index (VAI) and Vocalic Functional Ratio (VFR).

We hypothesized that speakers with DS will have a reduced size of the acoustic vowel quadrilateral as compared to TD speakers. Also, that speakers with DS will exhibit atypical geometries of the vowel quadrilateral, particularly in the low-vowel region (/ae/ &/a/).

BACKGROUND

Vowel formant frequencies in DS have been reported in several studies, but the results are not in complete agreement.

- Moure et al.[2] reported a smaller ratio of the F2 frequencies for the vowels /i/ and /u/, calling this ratio the "DS vocalic anatomical functional ratio."
- Bunton and Leddy[3] also observed a reduced range of F2 frequencies for vowels /i/ and /u/ as well as a general reduction in vowel acoustic space.
- Fourakis et al.[4] concluded that F2 frequencies for high vowels were reduced in DS but they did not find a reduction of the F2 difference between /i/ and /u/.

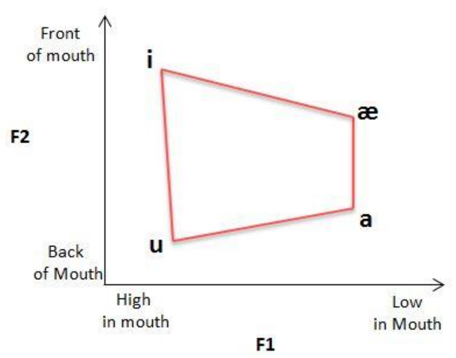


Figure 1. Acoustic vowel quadrilateral labeled to show articulatory-acoustic correlates. The area of the quadrilateral is a measurement of the acoustic contrast for vowels.

METHODS

Participants

48 individuals with Down syndrome (DS): 26 males and 22 females; ages 5.3 -to 36.9 yrs, mean age = 19.0 yrs.
75 typically developing individuals (TD): 34 males and 41 females; ages 4.4 to 66.4 yrs, mean age of 14.0 yrs.

Stimuli

Speech samples were obtained from a repetition task using 40 familiar monosyllabic words (e.g., "bead" and "bat"). The words were selected to represent the corner vowels. Each vowel was represented in 5 different test words. Stimuli were recorded with a Marantz digital recorder paired with a TOCS+ Platform (speech testing software) for randomization. Stimuli were presented visually and aurally.

Acoustic Analysis

The waveforms for each word were first segmented with the software Praat to select a vowel segment for formant analysis. Vocal fundamental frequency and the frequencies of the first three formants were measured with the software TF32. Formant frequency analysis was accomplished with Fast Fourier Transform (FFT) spectrograms overlaid with Linear Predictive Coding (LPC) formant tracks. If needed, a spectral slice was generated to show the FFT and LPC spectra calculated for the selected vowel segment.

DATA ANALYSIS

I. Graphic Display of Vowel Acoustic Space:

- Graphical displays of the vowel quadrilaterals were judged qualitatively with reference to developmental patterns summarized in Vorperian and Kent[5]. Data were assigned to developmental age groups: pre-pubescent (ages 4-10), pubescent (ages 10-15), post-pubescent (ages 15-20) and adult (ages 20+).

II. Quantitative measures of Vowel Acoustic Space:

- Two measures were obtained to assess differences in the size and configuration of the vowel quadrilaterals.
  1. Vowel Articulation Index (VAI)[6-8] = (F2i + F2a) / (F2u + F2a + F1u + F1i)
  2. Vocalic Functional Ratio (VFR)[2] = F2 /i/ ÷ F2 /u/

RESULTS:

Vowel Acoustic Quadrilaterals

As seen in **Figure 2** the vowel quadrilaterals in individuals with DS are different from those of TD participants. A frequently occurring abnormality is a poor distinction between vowels /a/ and /ae/, sometimes resulting in a collapse of the low-vowel portion of the vowel quadrilateral.

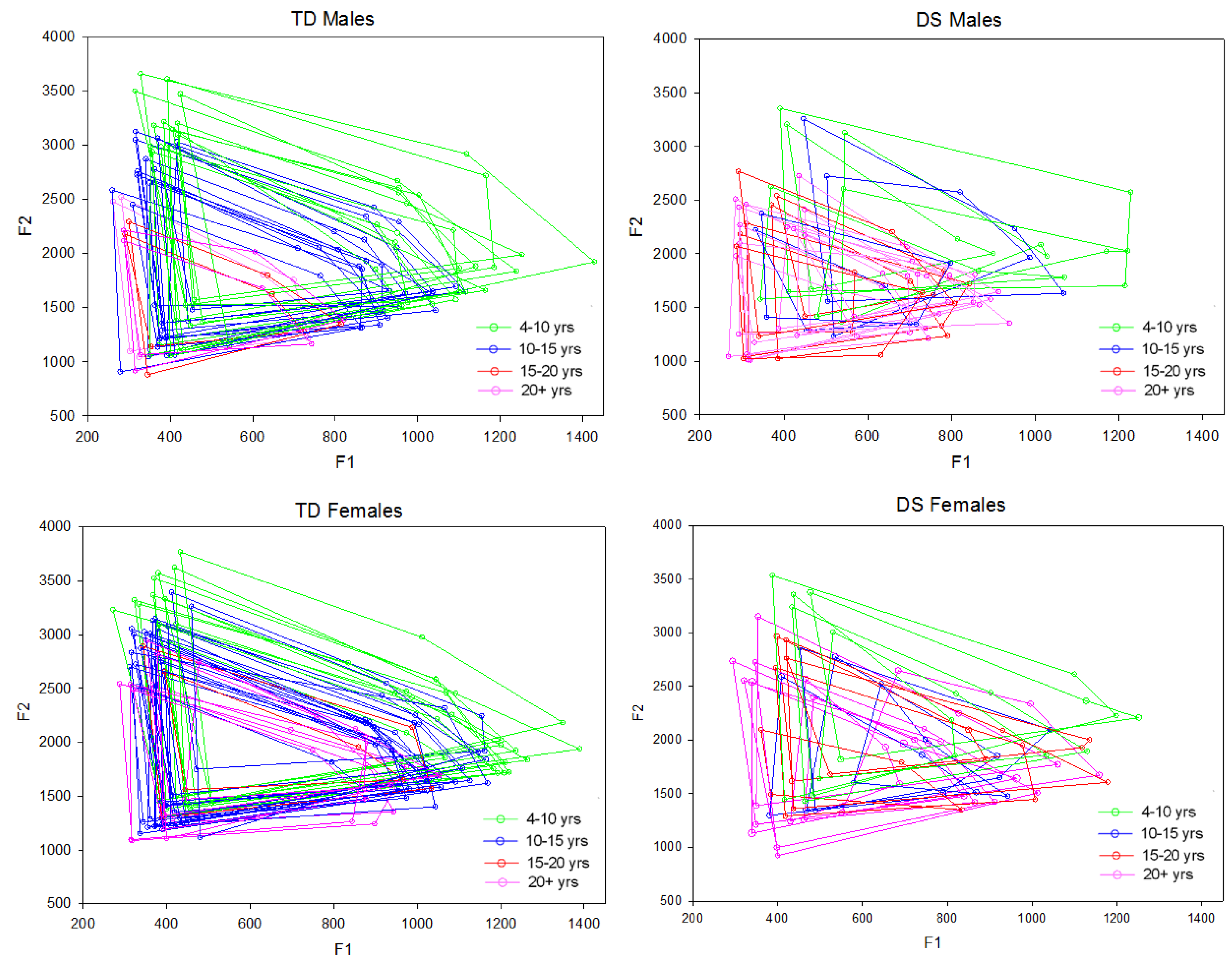
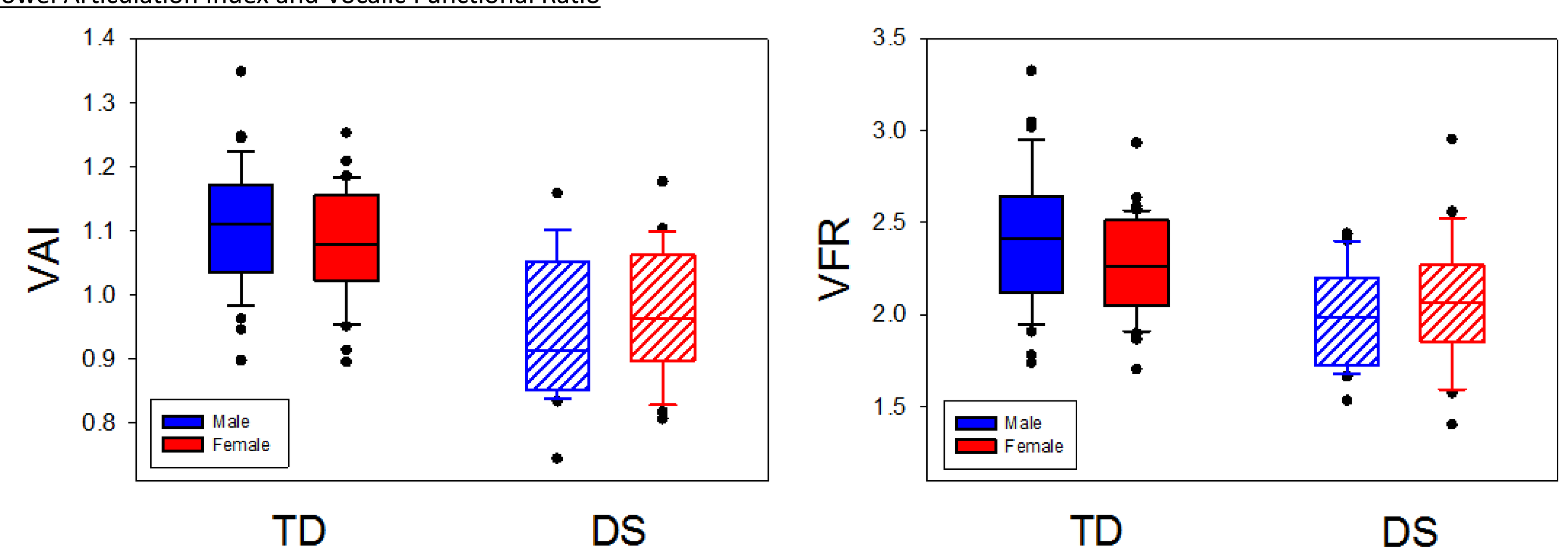


Figure 2: The vowel acoustic space for TD individuals (left column) and individuals with DS (right column). Participants are grouped into four age groups:
- Pre-pubescent (green)
- Pubescent (blue)
- Post-pubescent (red)
- Adult (pink).

Quantitative measures: Vowel Articulation Index and Vocalic Functional Ratio

Figure 3. Values for VAI and VFR for TD & DS speakers (male/blue, female/red). The box displays the 25th, 50th and 75th percentiles. The whiskers show the 10th and 90th percentiles. Data points outside of this range are displayed as black dots.



	All participants		Participants per age groups							
	All Ages		4-10 yrs		10-15 yrs		15-20 yrs		20+ yrs	
	DS	TD	DS	TD	DS	TD	DS	TD	DS	TD
VAI	M .95 (sd=.11)	M 1.11 (sd=.095)	M .94 (sd=.096)	M 1.14 (sd=.094)	M .93 (sd=.119)	M 1.1 (sd=.095)	M .98 (sd=.095)	M 1.01 (sd=.097)	M .94 (sd=.125)	M 1.06 (sd=.054)
	F .97 (sd=.1)	F 1.08 (sd=.087)	F .98 (sd=.072)	F 1.12 (sd=.075)	F .91 (sd=.074)	F 1.08 (sd=.08)	F .94 (sd=.114)	F .99 (sd=.137)	F 1.02 (sd=.113)	F 1.04 (sd=.088)
VFR	M 1.99 (sd=.26)	M 2.41 (sd=.376)	M 1.95 (sd=.234)	M 2.55 (sd=.408)	M 1.93 (sd=.262)	M 2.34 (sd=.357)	M 2.06 (sd=.267)	M 2.25 (sd=.49)	M 1.99 (sd=.292)	M 2.27 (sd=.2)
	F 2.08 (sd=.34)	F 2.27 (sd=.272)	F 2.13 (sd= .27)	F 2.39 (sd=.196)	F 1.94 (sd=.25)	F 2.26 (sd=.296)	F 1.82 (sd= .31)	F 1.96 (sd=.36)	F 2.28 (sd=.337)	F 2.17 (sd=.23)

Table 1. A comparison of values for Vowel Articulation Index (VAI) and Vocalic Functional Ratio (VFR). Results summarized for all TD and DS participants (M=Males, F=Females). Also, TD and DS (M & F) participants in different age groups.

SUMMARY OF RESULTS

1. Vowel quadrilaterals for TD and DS participants
   - Our results for TD participants are highly similar to those summarized by Vorperian and Kent[5] in showing a systematic developmental pattern in which values of F1 and F2 decline with age but maintain the expected pattern of a vowel quadrilateral defined by the corner vowels.
   - Our results for the DS participants show a less orderly developmental change in quadrilaterals, with conspicuous individual differences in the sizes and shapes of the quadrilaterals. For some participants, vowel distinctions are small or absent, especially for vowels /a/ and /ae/.
2. Vowel Articulation Index (VAI)
   - VAI values are higher for the TD participants, implying that individuals with DS tend to have centralized (less distinctive) vowels.
3. Vocalic Functional Ratio (VFR)
   - Our findings are comparable to Moura et al.[2]. The F2 ratio between /i/ and /u/ is reduced in participants with DS. This reflects a diminished articulatory adjustment in front-back tongue position for high vowels. A similar contraction is seen in the articulatory dimension between vowels /a/ and /ae/. These results point to a general loss of distinctiveness between front and back vowels.

CONCLUSIONS/ IMPLICATIONS:

1. Our findings confirm that vowel production is atypical in individuals with DS, particularly the back vowels /ae/ and /a/ and the high vowels /i/ and /u/.
2. Such findings may be relevant to the reduced speech intelligibility that individuals with DS typically experience.
3. The deficiencies in vowel production could be related to craniofacial anomalies, disrupted motor control, faulty phonological representation, or some combination of these. Uong et al.[9] concluded in a MRI study that DS is associated with a reduction in upper airway size resulting from soft tissue crowding within a smaller mid-face and lower-face skeleton. But motor problems, such as hypotonia, also could contribute to difficulties in articulator activity.
4. Acoustic measures of vowels are an objective index of articulatory ability in individuals with DS and could be used to assess the outcomes of interventions.
5. Studies of articulatory and phonological errors in DS have shown that the patterns are a complex blend reflecting both developmental errors and atypical errors[1]. Acoustic and physiological studies have potential to shed new light on these speech problems.
6. Speech difficulties in DS show phenotypical variation, but it appears that many individuals with DS have co-occurring disorders of voice, articulation, phonology, prosody, and fluency, all of which probably contribute to limitations in speech intelligibility[1]. Profiles of impairment in these different domains would help to characterize the nature of the communication disorder at both the individual and population levels.

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SELECT REFERENCES: This poster can be found at: http://waisman.wisc.edu/vocal/posters.html

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