

Developmental trends of speech acoustics in typically developing children and children with Down syndrome

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WHAT IS DOWN SYNDROME?

Down syndrome is a chromosomal disorder in which the individual has a partial or a whole extra copy of chromosome 21, which results in physical and intellectual differences. Communication problems are common in individuals with Down syndrome. Their speech often is characterized by reduced intelligibility and abnormal formant frequencies (the resonances of the vocal tract). The first two formant frequencies, F1 and F2, are most important for phonetic identification and are the primary focus of this study.

PURPOSE: To assess the developmental pattern of vowel acoustics in individuals with Down syndrome (DS) as compared to typically developing (TD) individuals.

- The speech of individuals with DS is typically reduced in intelligibility/clarity. For the purposes of this study, the focus is on the four extreme vowels as in the words 'heat-hoot-hat-hot'.
- These point vowels define a vowel acoustic space – shaped as a quadrilateral – that is reflective of the articulatory working space for vowels. Specifically, they represent the four corners of tongue position—high-front (/i/ heat), high-back (/u/ hoot), low-front (/ae/ hat), low-back (/a/ hot). See Fig. 1.
- Individuals with DS have distinct craniofacial features, such as smaller anterior facial skeleton, which results in a smaller oral cavity, and the appearance of a relatively larger tongue. Speech production in DS is likely affected by such anatomic anomalies as well as neuro-muscular problems, such as hypotonia.
- As children grow and acquire the sounds of their ambient language, their vocal tract (VT) anatomy also grows and there are consequent changes in the acoustic patterns of speech.
- This study examines vowel acoustic changes in a longitudinal study of children with Down syndrome as compared to typically developing individuals. Longitudinal research will aid the understanding of how speech production changes in development in individuals with DS.
- Based on findings to date, we hypothesized that:
 - The difference of the F2 frequencies for front (heat, hat) and back vowels (hoot, hot) will be smaller in DS participants than in TD participants. F2 is an indirect measure of tongue advancement. The smaller anterior facial skeleton in DS results in smaller oral cavities which in turn limits tongue movement and hence the reduced vowel acoustic space that is noted in individuals with DS. The F2 ratio measure has been reported in a previous cross-sectional study of vowel production in DS (Moura et al., 2008).
 - DS vowel production will be more variable than TD vowel production. This difference may exist for a variety of reasons, such as: DS participants may have a less stable phonological representation, problems with motor control, and/or anatomic anomalies.

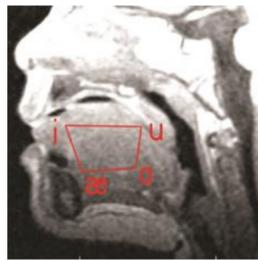


Figure 1. Midsagittal Magnetic Resonance Image of a DS one year old female (DS-F178-01-02) overlaid with vowel quadrilateral.

METHOD:

Participants: Using the Vocal Tract Development Laboratory's acoustics database, the following five speakers with DS (3 females and 2 males), who had participated three or more times in speech recordings over a period of 3-to-6 years, and were between the ages 4 to 17 years, were included in this study:

- DSF5020 (data collected at ages: 11;0, 12;1, 13;1, 14;1, 16;2)
- DSF5035 (data collected at ages: 14;5, 16;5, 17;4)
- DSF5047 (data collected at ages: 11;3, 13;3, 14;3)
- DSM5023 (data collected at ages: 4;5, 5;4, 6;5, 7;3, 8;4, 9;3)
- DSM5109 (data collected at ages: 10;00, 10;11, 11;11)

In addition, two different sets of control participants were selected per hypothesis. For the F2 differences hypothesis, the average /i/ and /u/ F2 values from 116 TD participants (59 male and 57 female) per age/group between the ages 4 to 18 years were used to compute the normative F2 /i/ minus F2 /u/ differences reference. To address the speech production variability hypothesis, TD participants were selected where for each of the five speakers with DS and for each age recorded, two typically developing participants who were matched for age, sex, and percentile growth (using DS or TD population specific growth standards) were selected as controls.

Speech samples consisted of the participants' repetition of twenty monosyllabic words containing the four corner vowels /i/, /u/, /ae/, and /a/ that were familiar to young participants, and had a high phonological neighborhood density that reportedly maximizes vowel space (Munson & Solomon, 2004). All speech samples were recorded in a quiet room using a Marantz digital recorder and a Sure microphone placed 15 cm for each speaker's mouth. The TOCS+ Platform Program (Hodge, Gotzke, & Daniels, 2009), hosted on a laptop computer, was used to randomly present the stimuli visually and aurally. Participants were asked to repeat each word at normal conversational loudness.

Acoustic Analysis: The recorded waveforms were first segmented and saved for each word using Praat software. Next, the vowel portion of each individual word was analyzed using the software TF32 to make formant frequency measurements, specifically F1 and F2.

Analysis: Using the average formant values for each speaker, the F2 /i/ minus F2 /u/ difference was calculated for each of the five DS participants, and also all TD participants. Differences values are plotted in Figure 2.

•Next, as a measure of comparing speech production variability, we calculated the difference in standard deviation between TD and DS speakers during the production of the four vowels. For each visit of the DS speakers and their TD controls, we first determined the standard deviation of the four formant frequencies for each vowel using 7 word repetitions. Next, we subtracted each TD SD value from the DS SD value. The differences are plotted in Figures 3a and 3b. The positive difference in SD values indicates that the DS speakers have more formant frequency variability than their matched controls.

RESULTS: Findings revealed DS speakers to have reduced F2 difference between the vowels /i/ (as in heat) and /u/ (as in hoot) measurements as compared to TD participants. See Figure 2. The F2 /i/ minus F2 /u/ differences were smaller in four of our five DS participants as compared to TD participants. As noted in the introduction, Moura et al. (2008) suggested reduced F2 ratio represents an anatomic limitation related to the relatively short oral cavity.

•Findings, as seen in Figures 3a for F1 and Figure 3b for F2, show the standard deviation differences between vowels produced by DS speakers minus TD speakers to be overwhelmingly large, indicating that DS speakers are more variable in their productions of vowels. The variability in F1 SD differences (Figure 3a) showed a weak developmental trend reflective of variability decreasing slightly as age increases. However, such a trend was not present for F2.

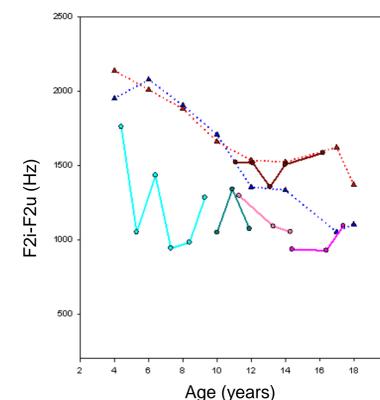


Figure 2: High front /i/ - back /u/ vowels' F2 differences for TD (dashed male-blue and female-red participants) and the five DS (2 males-blue hues and 3 females red hues participants).

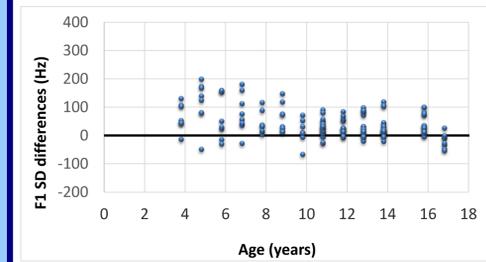


Figure 3a. F1 Standard deviation differences (DS minus TD) for all four vowels

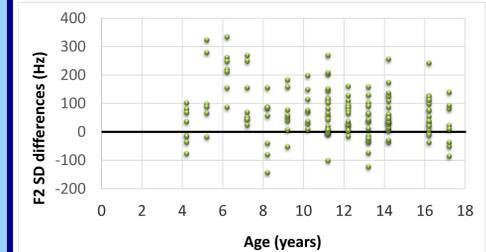


Figure 3b. F2 Standard deviation differences (DS minus TD) for all four vowels

CONCLUSIONS/IMPLICATIONS :

- This study confirmed the feasibility of using a longitudinal approach with a small number of participants to explore questions on vowel production variability in individuals with DS during the course of development.
- Individuals with DS produce vowels with reduced contrast and more variability than typically developing individuals.
- The reduced difference in F2 between /i/ and /u/ implies that individuals with DS have a reduced articulatory working space for vowel production. Vowel production in DS appears to be hindered by anatomic features, specifically the smaller/shorter oral cavity as noted by Moura et al. 2008.
- Four of our five DS speakers had reduced F2 ratio for /i/ and /u/. Additional investigations on the relation of this measure to speech intelligibility, as well as anatomic measurements of oral and pharyngeal cavities are warranted.
- The novel finding of greater variability in vowel production by DS speakers is likely to be rooted in phonological or motoric factors (or both).
- Both factors identified above may help to explain the reduced intelligibility in DS.
- Such findings warrant additional investigations using vowel specific analysis as well as using cross-sectional data from a larger number of DS speakers.

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