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Speech Intelligibility in Down Syndrome: A Developmental Perspective

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Objective: To identify phonetic properties that contribute to reduced intelligibility in speakers with Down syndrome ages 4 to 40 years. Intelligibility is defined as percentage of words identified correctly by listeners.

Introduction:

- Individuals with Down syndrome (DS) often have reduced speech intelligibility throughout the lifespan[1, 5, 6, 7].
- Consonants and vowels in all positions reportedly contribute to reduced intelligibility[1].
- Speakers with DS reportedly have a smaller mid- and lower facial skeleton, but a normal tongue size[4]. Consequently, tongue movement may be restricted during speech production (see **Fig. 1**)
- Acoustic analyses indicate that:
  - Children with DS ages 3-8 have reduced contrast between high vowels /i/ and /u/[9].
  - Speakers with DS ages 4-20 have reduced contrast in all dimensions of vowel production, particularly between low vowels /æ/ and /ɑ/[12] (see **Fig. 2**).
- Driven by such results, the **purpose** of this perceptual study was to investigate the phonetic properties of speech intelligibility in speakers with DS across the lifespan.

Figure 1. Vowel space overlaid on a mid-sagittal MRI view of a one year old female with DS.

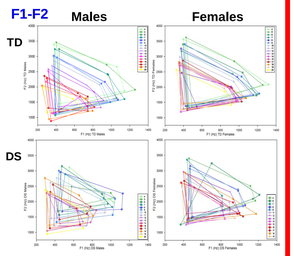


Figure 2: F1-F2 plots from 'Development of the Acoustic Vowel Quadrilateral: Normative Data and a Clinical Application' presented by Vorperian and Kent at 2014 Motor Speech Conference.

Research questions:

1. What is the developmental pattern of speech intelligibility in persons with DS?
2. What is the relative contribution of vowel and consonant errors to reduced intelligibility in DS?
3. Are some dimensions of vowel production more problematic than others for speakers with DS?

Methods:

Part I. Speech sample production

Participants:

- 64 speakers with DS (30 female, 34 male) ages 4 to 40 years. 38 speakers had repeat visits at multiple ages.
- 25 TD (typically developing) children (11 female, 14 male) ages 4 to 7 years for intelligibility comparison

Procedure:

- Speakers were asked to repeat 20 monosyllabic words containing one of the four point vowels. Words were presented randomly using the TOCS platform[3].
- Total number of speech recordings: 144 from speakers with DS, and 29 from TD speakers.

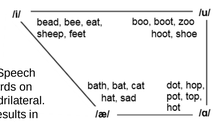


Figure 3. Speech sample words on vowel quadrilateral. Acoustic results in **Fig. 2** were also derived from these words.

Part II. Intelligibility – perceptual study

Participants:

- 54 adult TD listeners (18 male, 37 female) ages 19 years and older

Procedure:

- Speakers' recordings were normalized for amplitude and organized into groups of 5-7.
  - Each group of speakers with DS included males, females, adults, and children.
  - Each group of TD speakers included males and females ages 4-5 or 6-7 years.
- Listeners heard and transcribed one group of speakers per session and participated in 2-3 sessions on different days.
- Each group of speakers was transcribed by five different listeners.

Listening Task:

- Before participating, listeners:
  - Passed a hearing screening.
  - Viewed a list of target words to reduce learning effects.
- For the task:
  - One word at a time was presented to listeners through headphones.
  - Listeners were instructed to type what they heard, not what the speaker was trying to say.
  - All words from each speaker were presented before hearing the next speaker.
- An in-house programmed software randomized word order within each speaker and speaker order within each group.

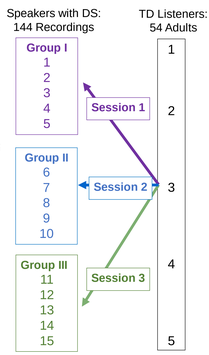


Figure 4. Listening task design

Data Analysis:

- Another in-house programmed software analyzed listeners' responses.
  - Responses were compared to the target words using the Carnegie Mellon University Pronouncing Dictionary[2].
  - Listeners' identification of the word, vowel, initial consonant, and final consonant were scored as correct or incorrect.
- Manual editing was completed to:
  - Score responses the dictionary did not recognize as words.
  - Verify scoring accuracy.
- The software program computed the average percent correct across all listeners' responses for:
  - Words, total vowels, total consonants, initial consonants, and final consonants per speaker.
  - Point vowels per speaker.

Statistical Analysis:

- Mixed effects with a random intercept for each participant were used in all models to account for participant heterogeneity and correlation of multiple visits.
- Plots revealed that age and each of the phonetic properties had a non-linear relationship with words correct.
- Fractional polynomials were used to fit models and select the best-fitting transformation.
  - Developmental trend: Age and sex were used as predictors (see **Fig. 6**). Best-fitting transformation of age was the inverse (1/age).
  - Phonetic properties: Separate models were fit for each phonetic property to examine the strength of the relationship to words correct. Sex and 1/age were included in each model. Best fitting transformation was the square (phonetic property squared).

Results:

- **Figures 5a-5b** show considerable individual variability in speakers with DS. Individuals with multiple visits did not always improve across visits, and reduced intelligibility persisted into adulthood for some speakers.
  - Intelligibility in TD children improved through 7-8 years of age. Majority of speakers with DS of all ages were less intelligible than TD speakers 7-8 years of age.

Figure 6

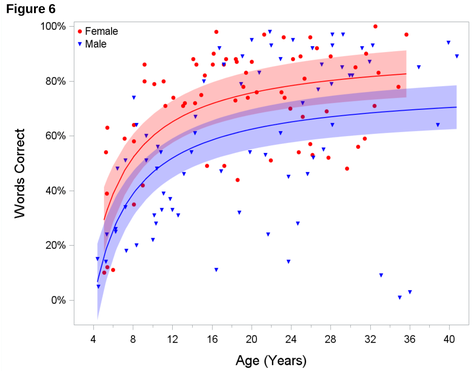
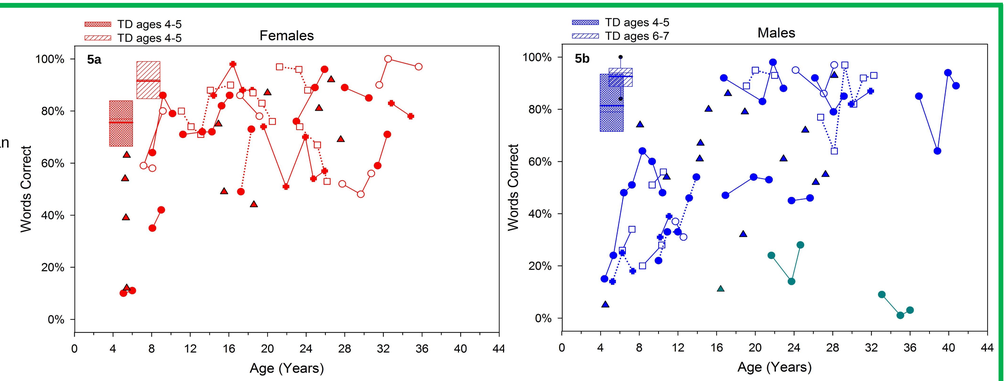


Figure 6. Words correct for speakers with DS. Lines indicate mixed models and bands indicate 95% confidence bands, with sex and 1/age as predictors. A random intercept for each speaker was included in the model.



Figures 5a-5b. Words correct for all speakers. Line plots indicate speakers with multiple visits, and triangles indicate speakers with one visit. Analyses with and without outliers (shown in teal) are described below. Striped box plots show TD speakers' data for comparison.

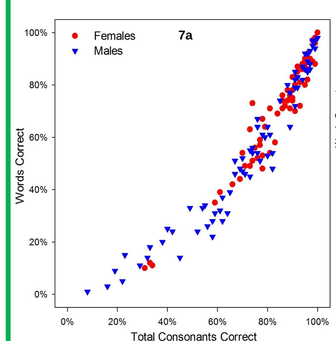
- **Table 1** shows that all phonetic properties significantly contributed to reduced intelligibility in speakers with DS, although some contributed more than others.
- In descending order, variables most correlated with words correct were: total consonants, initial consonants, final consonants (see **Figs. 7a-c**), total vowels, /ɑ/ vowels, /æ/ vowels, /i/ vowels, and /u/ vowels (see **Figs. 8a - 8e**).

Table 1

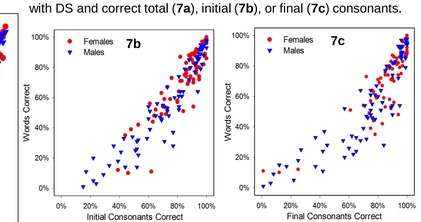
Phonetic properties	F(1,79)	p-value
Total consonants correct	1788.43	<.0001*
Initial consonants correct	391.40	<.0001*
Final consonants correct	230.55	<.0001*
Total vowels correct	206.13	<.0001*
/ɑ/ vowels correct	79.77	<.0001*
/æ/ vowels correct	51.94	<.0001*
/i/ vowels correct	8.15	.0055*
/u/ vowels correct	4.40	.0391*

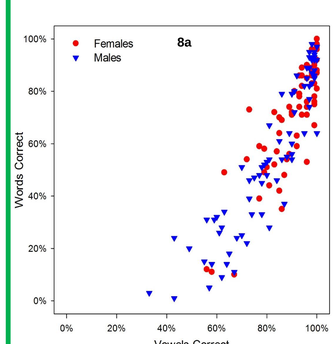
Table 1. Significance of phonetic properties as predictors for words correct in mixed models including 1/age, sex, and a random intercept for each subject. All of the phonetic properties were squared due to a curvilinear relationship with words correct. Each result above represents a different model.

- **Figure 6** shows that intelligibility increased significantly with age in speakers with DS (F (1, 79) = 65.16, p < .0001), with larger rates at younger ages.
  - Although females with DS were significantly more intelligible than males (F (1, 61) = 6.28, p = .0149), this difference was no longer significant when 3 male speakers over age 16 with less than 30% words correct were excluded (see blue-green plots in **Fig. 5b**).

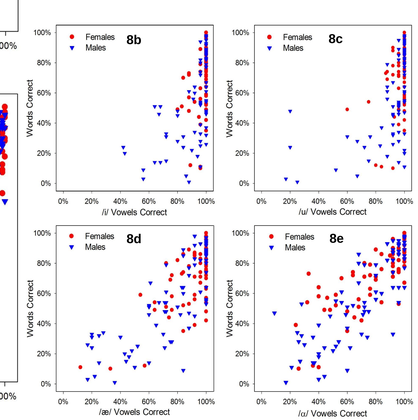


Figures 7a-7c. Relationship between words correct for speakers with DS and correct total (**7a**), initial (**7b**), or final (**7c**) consonants.





Figures 8a-8e. Relationship between words correct for speakers with DS and correct total vowels (**8a**) or point vowels (**8b-8e**).



Discussion:

1. As an overall trend, intelligibility improved significantly with age. However, individual variability was marked and some speakers showed severely reduced intelligibility, even in adulthood.
2. Both consonants and vowels contributed to reduced word intelligibility. Consonants contributed more than vowels, perhaps because there were twice as many consonants as vowels in 15/20 words. Initial consonants contributed more than final consonants.
3. Low vowels /ɑ/ and /æ/ contributed more than high vowels /i/ and /u/. This could be due to production features of the low vowels:
   - Tongue-jaw coordination needed for precise production
   - Little tactile feedback between the tongue and the maxilla
   - More restricted tongue movement between the low vowels than between the high vowels
4. Results of this perceptual study combined with acoustic analyses derived from the same words (see **Fig. 2**) provide insights into the basis of reduced speech intelligibility, and are in line with documented anatomic dysmorphology.

Implications for research and clinical intervention:

- Reduced speech intelligibility in DS is likely due to multiple factors, including: craniofacial dysmorphology, speech motor impairment (hypotonia along with articulatory placement and sequencing disorders), hearing loss, and cognitive limitations[5].
- Future research that collects longitudinal data would allow examination of individual developmental patterns in intelligibility. Intelligibility data combined with anatomic and acoustic data on the developing vocal tract can help identify the role of the developing anatomy on the articulatory space.
- Ideally, an assessment should be developed that uses common words and sentences to assess speaker-specific intelligibility patterns to devise an optimal intervention plan. Treatment for both vowels and consonants may be effective, since both can contribute to reduced intelligibility. In behavioral interventions for specific vowels[10], targeting low vowels is recommended because they are more related to intelligibility reduction than high vowels. These treatments could be included in a general intervention plan, such as that described by Swift & Rosin[11].
- Because reduced intelligibility in DS could be due to anatomic limitations, interventions that directly alter the anatomy of the orofacial complex, such as a stimulating palatal plate[8], should also be considered. Collecting sex-specific longitudinal anatomic and acoustic data to assess the effects of such interventions on speech intelligibility is warranted.

Conclusion:

- In general, intelligibility improved with age. However, there was considerable speaker variability.
- Majority of speakers with DS across the lifespan were less intelligible than TD speakers ages 7-8 years.
- All phonetic properties examined here contributed to reduced intelligibility, with consonants contributing more than vowels, initial consonants contributing more than final consonants, and low vowels contributing more than high vowels.

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