QUANTIFYING COMPLEXITY OF CHILDREN'S TONGUE CONTOURS USING ULTRASOUND IMAGING

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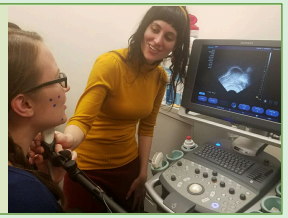
INTRODUCTION

- Broad generalizations about the order in which speech sounds are added to a child's phonetic inventory are represented by normative values. (Smit et al., 1990)
- Developmental speech patterns reflect combination of phonological knowledge (Boersma, & Hayes, 2001; Tesar & Smolensky, 1998) and motor control of speech structures; relative contribution from these two domains is not fully understood. (McAllister Byun & Tessier, 2016)
- In early stages of development (Green et al., 2000) and disorders (Gibbon, 1998), a lack of differential lingual control (i.e., the inability to isolate control of anterior versus posterior regions) may play a role in children's non-adult-like speech patterns.
- It is hypothesized that speech sounds can be sorted into classes of articulatory complexity (Dawson, Tiede, & Whalen, 2016).
  - There is currently no objective measure for classifying productions into categories of lingual complexity.
  - Differences in lingual complexity may be related with articulatory markedness and order of acquisition.

The goal of this study is to establish and explore the utility of several potential methods for measuring the degree of complexity of a given lingual contour.

APPROACH

1. Extract contours from ultrasound images of adults (Dawson et al., 2016) and children producing various target phonemes.
2. Select metrics corresponding best with gestalt impression of complexity.
3. Test whether potential metrics of lingual complexity can sort productions by:
   a) Complexity categories proposed by Dawson et al. (2016)
   b) Adult versus child speakers
   c) Perceptual accuracy within child speakers



ADULTS

Dawson, Tiede, & Whalen (2016)

- Asked which metrics best separated adult productions of vCv and cVc nonwords into complexity classes.
- Used *a priori* categories of complexity for adult speech sounds:
  - Low: /ɑ/, /æ/, /ɪ/, /ʌ/, /ɛ/
  - Medium: /w/, /u/, /j/, /g/
  - High: /d/, /l/, /ɹ/, /θ/, /ʒ/
- Used three techniques to sort tongue contours into complexity categories.
  - Modified Curvature Index (MCI)
  - Procrustes Analysis
  - Discrete Fourier Transform (DFT)

CHILDREN

METHOD

- Elicited target phonemes at the word level from 7 preschool-aged children (4;0-6;3).
- Used GetContours (Tiede, 2016) to trace contours of best frames within intervals for each sonorant, vowel and stop burst (Fig 1).
- Computed metrics as with adults. (Dawson et al., 2016; Dawson, 2016)
- Grouped productions by complexity. (as in Dawson et al., 2016)

Low	Medium	High
(21 total):	(23 total):	(34 total):
✧ /æ/ (cat, lamb, rat, yam)	✧ /w/ (wake, wing)	✧ 9 /t/ (tape, tea, toe)
✧ /ɪ/ (ring, wing)	✧ /j/ (yam)	✧ 7 /l/ (lake, lamb)
	✧ /k/ (cape, cat, coat, key)	✧ 18 /ɹ/ (rake, rat, ring, rope)

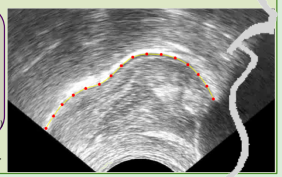


Figure 1 (right). In GetContours, points were tagged along each lingual contour. Pictured in this image is an /ɹ/ production within the word "rake."

What is an intuitive measure of tongue complexity?

- In Dawson et al. (2016), Procrustes and especially DFT metrics are opaque to intuition (i.e., more complex shapes did not necessarily have extreme values).
- However, MCI does correspond with intuition, such that high values are visibly more complex.
  - MCI is an averaging technique that integrates curvature with length of the arc (Stolar and Gick, 2013) and minimizes difference between two adjacent points.
- Preston, McCabe, Tiede, and Whalen (2015) established a metric representing the number of inflection points (**NINFL**) along a lingual contour, which is also intuitive. (Fig. 2)

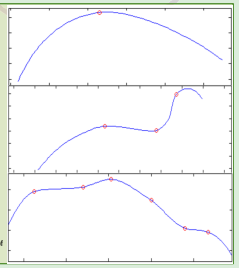
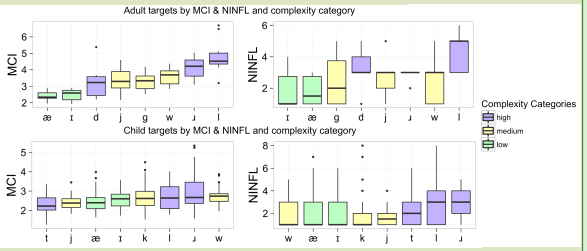


Figure 2 (right). Example contours demonstrating relationship between number of inflection points and complexity of lingual contours, from Preston et al., (2015).

COMPARING CONTOURS

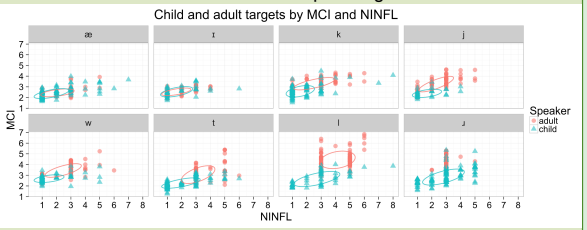
How robust are the proposed complexity categories? (Dawson et al., 2016)

- **Adults**
  - MCI separated /l/ and /ɹ/ from other targets.
  - MCI and NINFL separated low complexity (/æ/, /ɪ/) targets.
  - No clear partitioning in medium complexity group.
- **Children**:
  - NINFL separated /l/, /ɹ/, and /t/ from other targets.
  - No clear partitioning in low and medium complexity group.
- Overall, measures pick out lowest and highest (but not medium) complexity phonemes; differences between adults and children.



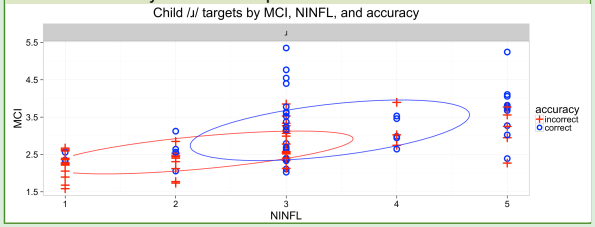
How well did MCI and NINFL separate child from adult targets?

- /æ/ and /ɪ/ not well separated (low complexity).
- /j/, /k/, /w/ (medium complexity) and /t/ are somewhat separated.
- /l/ and /ɹ/ are well separated (high complexity).
- Suggests that child and adult targets differ in complexity, and this difference increases in more complex targets.



How well did MCI and NINFL separate /ɹ/ productions by accuracy?

- Among child speakers, higher MCI and NINFL values were associated with more correct productions than low values.
- Suggests that correct productions have greater lingual complexity than incorrect productions.
- However, not able to classify fully based on these measures because only moderate separation of correct vs. incorrect.



CONCLUSIONS

- The present study highlights the relatively early state of the science of measuring differences in lingual complexity, especially in children.
- However, establishing such measures will be vital for understanding how motor factors influence the course of phonetic and phonological development.
  - Understand role of articulatory complexity and markedness, in relation with order of acquisition.
    - Congruent: /l/ and /ɹ/ are *late* developing, *marked*, and *lingually complex*.
    - Incongruent: /t/ is *early* developing and *unmarked*, but *lingually complex* (by some measures).
- Explore alternatives to the complexity categories from Dawson et al. (2016), considering:
  - Age of acquisition
  - Articulatory markedness
- In the future, these measures could also be useful in clinical research and practice:
  - Recommendations for motoric vs. phonologically-oriented approach to intervention.
  - Quantify a baseline level of articulatory complexity and track progress.

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