Production of fricative consonants in French-speaking children with cochlear implants and typical hearing: acoustic and phonological analyses.

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Introduction

- Children with cochlear implant (CI) have difficulties in the production of fricatives compared to age-matched peers with typical hearing
  - Specific and lasting difficulties due to degraded auditory input via the implant ? = auditory-based hypothesis
  - Or, simply, chronologically delayed acquisition profile?

→ Study of the production of fricatives by French-speaking children

- Phonological data (phonological accuracy, error patterns)
- Phonetic data (acoustic measurements designed to assess their articulatory and aerodynamic characteristics)

+ Relations between phonological and phonetic data

Material and methods

- Participants
  - 47 French-speaking children with typical hearing TH (56 ±13 months)
  - 23 French-speaking children with cochlear implant (CI) (67±15 months)

Table 1: *Participants in each age subgroup*

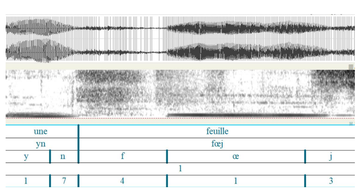
Group	Chronological age subgroups	Auditory age subgroups
CI	3;7-4 (7), 4;7-5;6 (6), 5;7-7y. (11)	3;7-4 (12), 4;7-5;6 (7), 5;7-7y. (5)
TH	2;6-3;6 y. (9), 3;7-4 (10), 4;7-5;6 (17), 5;7-7y. (11)	N/A (typical hearing)

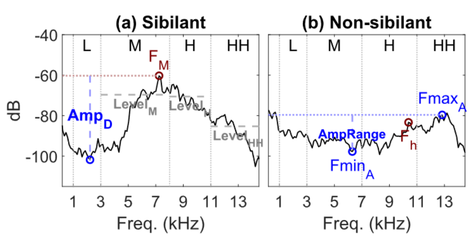
- Image naming task
  - The speech material includes 25 fricatives in high-frequency, low age of acquisition words -> total of 1941 analysed fricatives
- Phonological annotations using Phon 3.1
  - Percentage of Correct Phonemes (total, nasal vowels, fricatives, and stop consonants)
  - Percentage of various types of production errors

    Changes in manner of articulation (fricativization; stopping),

    Changes in place of articulation;

    Substitutions between voiced and voiceless consonants
- Automatic extraction of acoustic measures using Praat *Following Shadle et al., 2023*
  - 3 MultiTaper Power Spectra (8 tapers) per segment: beginning, middle, end of segment
  - For each sibilant target /s,z,ʃ,ʒ/: spectral peak, levelD, and ampDiff
  - For each non-sibilant target /f-v/: ampRange





- Statistical analyses: GLMM (lme4 package, R)
  - Dependent variables: Acoustic metric variables; percentages per child for phonological data
  - Independent variables: subject-related characteristics (auditory status, chronological/auditory age group), stimulus characteristics (fricative time point, fricative identity, place of articulation and voicing mode), and their interaction
  - Speaker as a random effect

Results

- Phonological analysis

Percentages of correct productions:

PCPhonemes: CI: 75% << TH: 91.1%

PCFricatives: CI: 72.1% << TH: 90.4%

In TH, PCP and PCF increase significantly with age

In CI, no effect of chronological or auditory age groups

Errors:

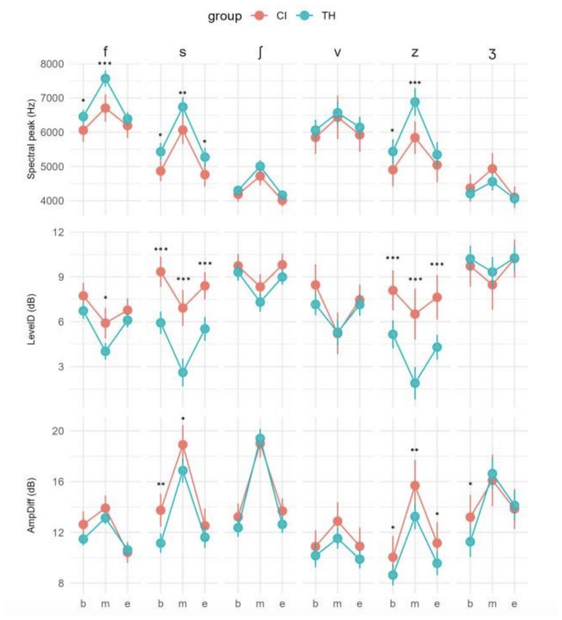
In both groups, the most frequent errors involve substitutions between voiced fricatives and substitutions between the phonemes /s/ and /ʃ/

In CI, fricativization errors (10%), stopping errors (4.2%) and voicing errors (4.8%) are found whereas they are virtually absent in TH.

In CI, only substitutions between /s/ and /ʃ/ decrease with chronological age, as well as fricativization errors with auditory age.

- Acoustic analysis

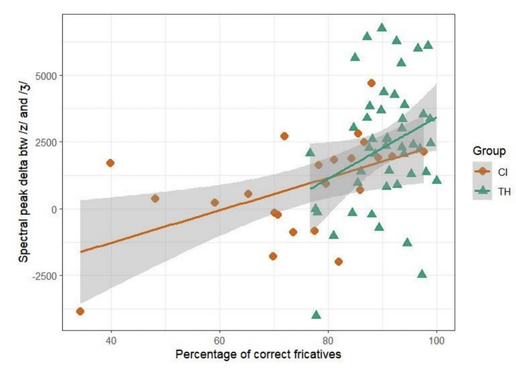
For all 3 measures, many significant differences as a function of:
- group (CI vs. TH),
- stimulus characteristics (fricative time point, fricative identity, place of articulation and voicing mode),
- and their interactions



- Relations between phonological and acoustic data

The mean values per subject and per phoneme for each type of acoustic measure were computed, then mean differences were computed between /f/-/s/, /s/-/ʃ/, /v/-/z/, /z/-/ʒ/ (differing in place of articulation) and between /f/-/v/, /s-z/, /ʃ-ʒ/ (differing in voicing)

A **positive correlation** was observed between the percentage of correct fricatives and the average spectral peak values difference between /z/ and /ʒ/ (both groups), between /s/ and /ʃ/ (CI) and between /v/ and /ʒ/ (TH)



In CI, **negative correlations** between fricativization errors and spectral peak mean differences for /v-ʒ/, as well as stopping errors and spectral peak mean differences between /s/ and /ʃ/ (r=-0.45; p=0.03) and /z-ʒ/ (r=-0.53; p=0.009).

Discussion

Phonological analysis

Lower accuracy percentages, encompassing all phonemes, and lower percentages of correct fricatives were observed in the CI group. Although certain error patterns (stopping, devoicing) are consistent with Kim & Chin's (2008) hypothesis of a similar but chronologically delayed development compared to typically hearing peers, the prevalence of certain atypical errors (fricativizations, voicing), and the fact that these different error types do not decrease with chronological/auditory age, seems more in line with the auditory-based hypothesis.

Acoustic analysis

All the acoustic characteristics observed in the CI group appear entirely consistent with the known limitations of signal processing by the implant. Indeed, if the implant cannot accurately encode the entire high-frequency range, it may not be capable of transmitting relevant information to 1) distinguish between voiced and voiceless fricative segments and the appropriate degree of constriction; 2) capture higher frequency spectral peaks such as /f, v, s, z/, consequently impacting productive skills.

Relations between phonological and acoustic data

We observed that children in the CI group with better distinction of the /s-ʃ/ and /z-ʒ/ segments by spectral peak values, as well as voiced/voiceless segments by AmpDiff values, also had the highest percentage of correct fricatives and fewer errors in fricativization/occlusivication. This relationship appears consistent with the auditory-based hypothesis of the phonological difficulties of CI users

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