Perception of voice gender in children's voices by cochlear implant users

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Questions

When listening to the speech of children

- What acoustic cues do listeners use to identify the gender of the talker?
- How does age perception connect to voice gender perception (VGP)?
- What happens when these cues are distorted or eliminated, as occurs in cochlear implant (CI) processing?

Background

- **Acoustic cues of voice gender**
  - Acoustic cue manipulation paradigms can reveal which cues listeners use [2, 5, 9]
  - Fundamental frequency (F0) and formant frequencies (FFs) are key [5]
  - However, F0 and FFs are not the only cues listeners use [2, 9]
- **Voice gender in children's speech and the role of age perception**
  - In children, average F0 and FFs vary systematically with age as well as gender (see Figure 1)
  - Previous research showed accurate age perception plays an important role [3]
  - Relatively accurate age perception has been demonstrated in children's speech [1]
- **VGP by CI users**
  - CI users have limited VGP abilities [4, 7]
  - Poor VGP possibly due to limited access to F0 and FFs [7, 4]
  - Good temporal resolution could help CI users use F0 in VGP [4]
  - Good spectral resolution could help CI users use FFs in VGP [4]
- **Significance**
  - VGP tasks may be useful to measure availability of spectrotemporal cues in CI users [8]
  - Talker identity cues play a role in speech perception

Methods

- **Stimuli:** /hVd/ syllables spoken by children from the North Texas area (age range: 5-18 years, medial vowels: /i/, /a/, /u/)

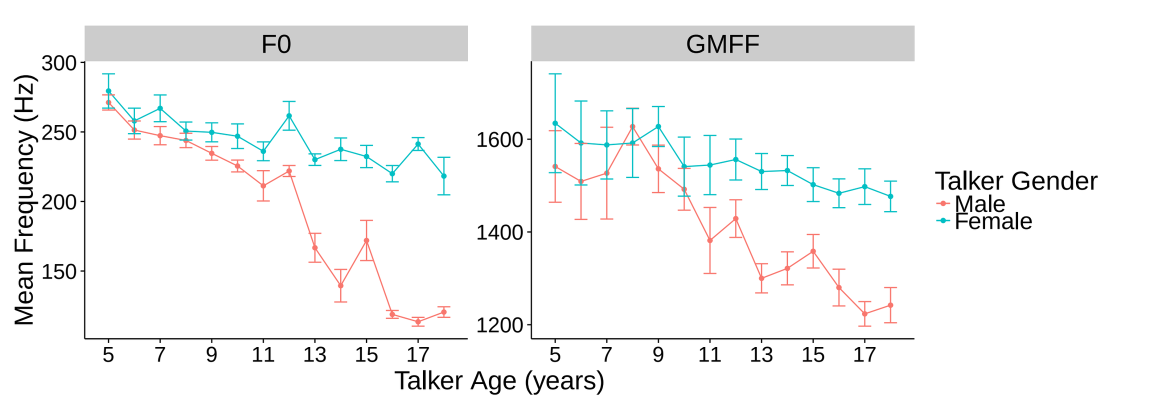


Figure 1: Mean F0, geometric mean of first three formants (GMFF) Values averaged across talkers and tokens within each gender. Error bars show ±1 standard error of the mean.

- **Task:** Participants listened to isolated syllables presented in randomized order and made two responses: (1) **Voice Gender** (two-alternative forced choice) and (2) **Age** (continuous scale, graphical slider, range: 5 – 18 years)

- **Acoustic Cue Conditions:** STRAIGHT vocoder [6] used to scale F0 contours and/or FF contours to opposite-sex averages at each talker age level

Unswapped	Original F0 and FFs
FF Swapped	Original F0, scaled FFs
F0 Swapped	Scaled F0, original FFs
F0FF Swapped	Scaled F0 and FFs

- **Experiments:**
  - **NH** 81 normal hearing (NH) adults
  - **VO** 37 NH adults attending to tone vocoder CI simulation
  - **CI** 5 CI users

Age	60	70	55	60	74
Age of implantation (L/R)	53/55	65/64	57/56	57/∅	52/∅
Age of hearing loss (L/R)	30/30	52/52	0/0	2/2	1/1
Device type (L/R)	N6/N6	N5/N5	N5/N5	Naida/∅	N6/∅

- **Other Details**:
  - **NH** and **VO** listeners completed one condition each
  - **CI** users completed a reduced set including all 4 conditions using only best implanted ear
  - 8 channel tone vocoder implemented according to specifications in [4], 160 Hz envelope cutoff
  - Stimuli presented monaurally over headphones (NH listeners) or in free field (CI listeners)

Results

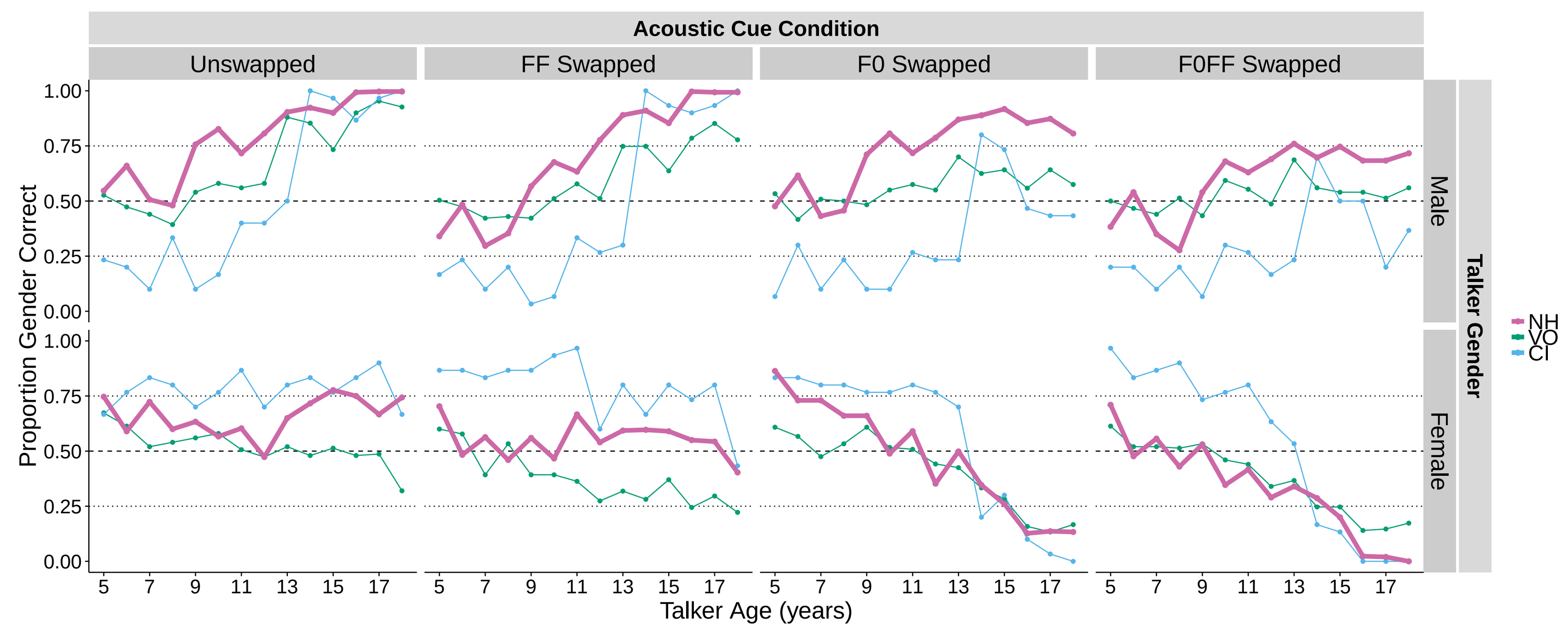


Figure 2: Proportion gender correct Each panel shows a different combination of acoustic cue condition and talker gender, while line color indicates listener group.

- Majority of male talkers correctly identified...
  - by NH listeners after 9 years of age
  - by CI listeners after 13 years of age
- CI listeners answered female for most younger talkers
  - Explains why CI listeners had higher proportion gender correct than NH listeners for female talkers
- Listeners answered male for many older females in Unswapped
- Across talker age, talker gender, and experiment, scaling F0 had larger effect than scaling FFs
- Effect of acoustic cue condition interacted with talker age, talker gender, and experiment

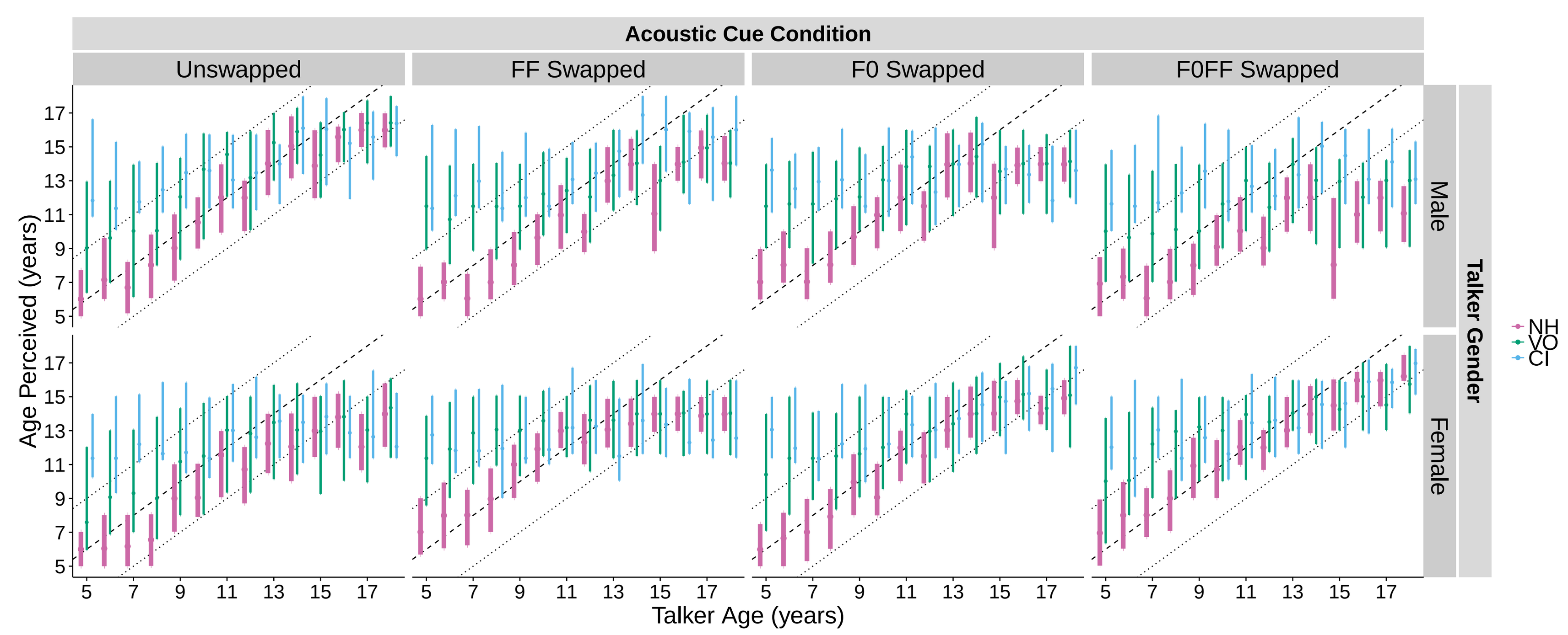


Figure 3: Median age perceived Each panel shows a different combination of acoustic cue condition and talker gender, while line color indicates listener group. Error bars indicate upper and lower quartiles.

- VO and CI listeners overestimated age of younger talkers
- Most listeners underestimated age of older female talkers in Unswapped
- Across talker age, talker gender, and experiment, scaling F0 had larger effect than scaling FFs
- Results in Unswapped mirror results for opposite talker gender in F0FF Swapped
- Correspondence between errors in VGP and errors in age perception suggests link

Model of VGP Data

- **Type:** Multilevel logistic (GLRM) model
- **Predictors:** Talker age, talker gender, age estimation error, acoustic cue condition, experiment (and interactions)
- **Implementation:** Implemented via lme4 package in R
  - Correct voice gender responses coded with a 1 and incorrect responses with a 0
  - Outcome variable was denoted $y_{i(jk)}$, for the i-th measurement from listener j to a stimulus spoken by talker k
  - Intercepts were allowed to vary between listeners and talkers

$$\text{logit}(y_{i(jk)}) = X_{i(jk)}\beta + u_j + v_k \mid u_j \sim N(0, \sigma_u^2), v_k \sim N(0, \sigma_k^2)$$

Model Analysis

Questions: To what extent did particular listeners make correct voice gender responses? To what extent was the voice gender of particular talkers correctly identified?

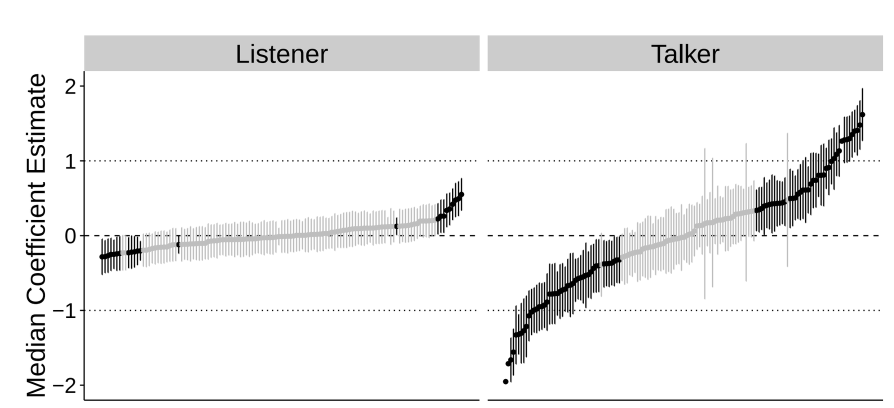


Figure 4: Median estimates of random intercepts for talkers and listeners Error bars indicate ±2 standard deviations. Grey intervals indicate intersection with 0.

- More variation explained by talker than listener intercepts

Question: How did listeners perform in the Unswapped condition when they identified talker age accurately?

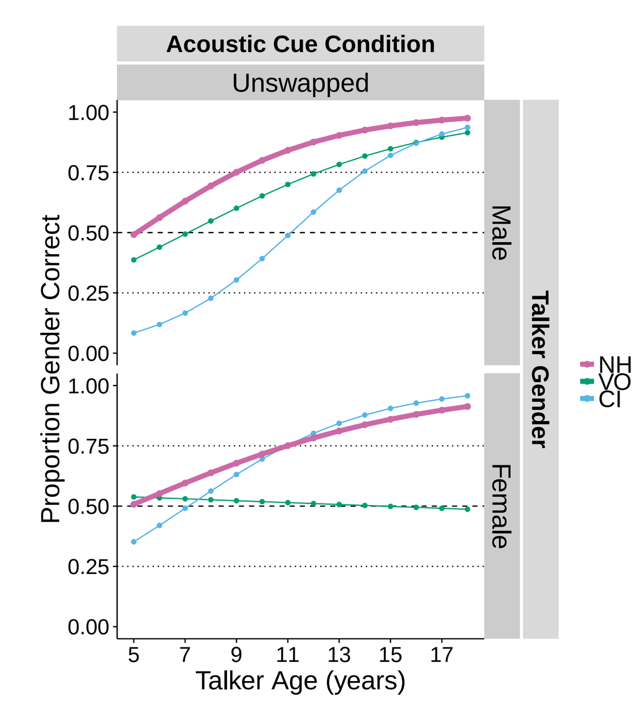
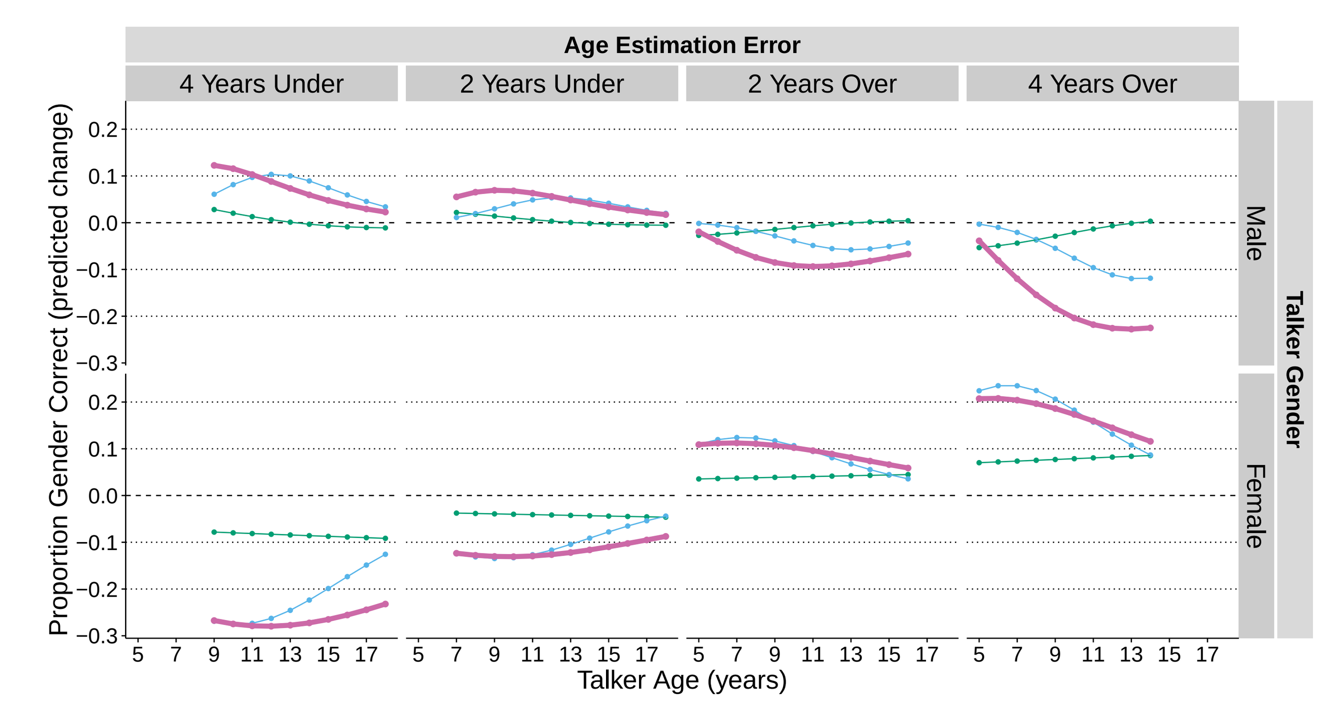


Figure 5: Predicted proportion gender correct given perfect age estimation, Unswapped Panels and line color indicate the same as in Figures 2 and 3. Intercepts for listener and talker were selected to be zero (i.e., predictions here correspond to 'average' talkers and listeners).

- Listeners made more correct responses to older talkers and male talkers
- Constitutes a baseline for comparisons in Figures 6 and 7

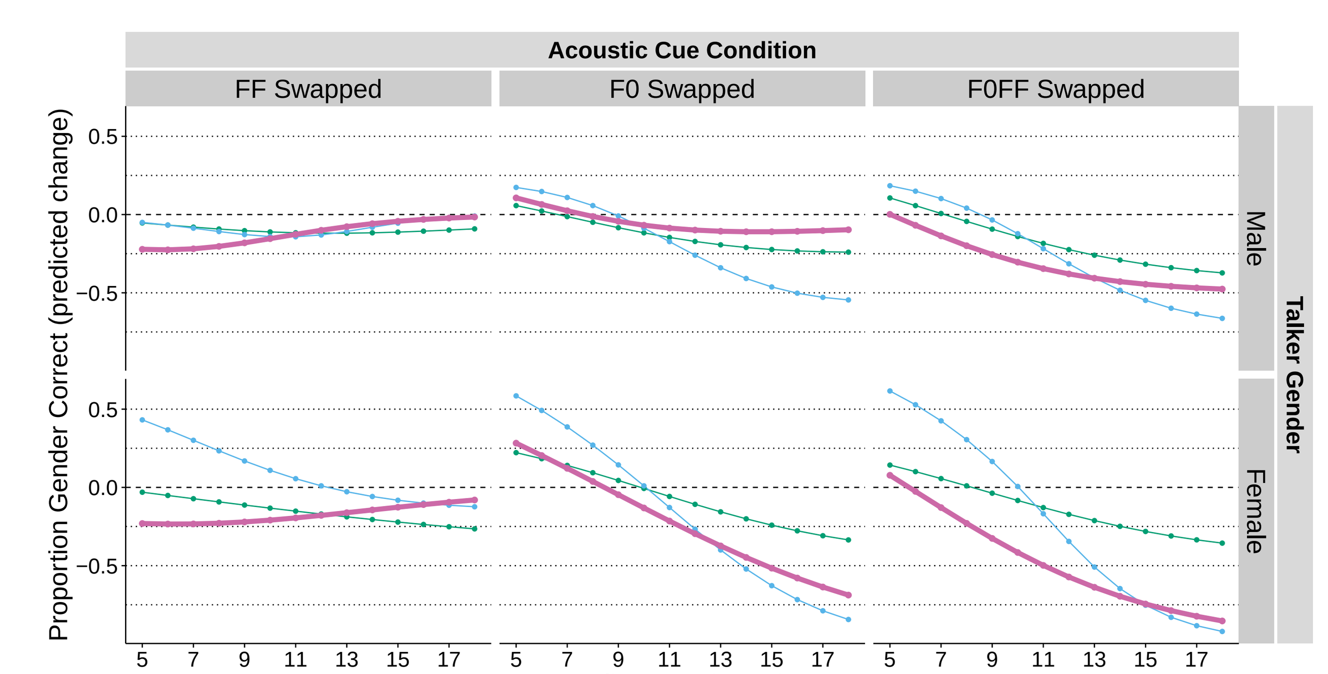
Model Analysis (continued)



Question: How was VGP affected when listeners under- or overestimated the age of the talker?

Figure 6: Predicted change in proportion gender correct at different levels of age estimation error, Unswapped Plotted relative to baseline in Figure 5. Each panel shows a different combination of age estimation error and talker gender. Line color indicates listener group. Impossible combos of age estimation error and talker age are not shown.

- Underestimating age of older female talkers linked to VGP errors
- Overestimating age of younger male talkers linked to VGP errors



Question: How was VGP affected by different acoustic cue conditions?

Figure 7: Predicted change in proportion gender correct in different acoustic cue conditions Plotted relative to baseline in Figure 5. Panels and line color indicate the same as in Figures 2 and 3. Here, age estimation error is fixed at 0 years.

- Swapping both cues usually had larger effect than swapping one cue for NH listeners
- Swapping both cues often had similar effect to swapping only F0 for VO and CI listeners

Summary and Conclusions

- For NH listeners...
  - Accurate age perception tied to accurate VGP
  - Older female talkers frequently mis-identified as younger male talkers
  - Utilized both acoustic cues, but FFs more important for VGP of younger talkers and F0 for VGP of older talkers
- For CI listeners...
  - Depended more on F0 than on FFs in VGP task
  - Younger male talkers frequently mis-identified as older female talkers
  - Errors likely due to combination of poor age perception and heavier reliance on F0
- Future directions
  - For NH listeners, scaling both cues did not flip VGP of older male talkers — may need to investigate modifying other acoustic cues (e.g., properties of the voicing source)
  - Utilize more advanced acoustic simulations of CIs to address VO - CI discrepancies
  - Statistical modeling of link between acoustic properties and VGP/age perception

References

[1] Ofer Amir et al. "Identification of Children's Gender and Age by Listeners". In: *Journal of Voice* 26.3 (2011), pp. 313–321.

[2] Peter F. Assmann, Terrance M. Nearey, and Sophia Dembling. "Effects of frequency shifts on perceived naturalness and gender information in speech". In: *Proceedings of the Ninth International Conference of Spoken Language Processing* (2006), pp. 889–892.

[3] Peter F. Assmann et al. "Links between the perception of speaker age and sex in children's voices". In: *The Journal of the Acoustical Society of America* 138 (2015). Poster presented at the ASA Jacksonville 2015 Meeting, p. 1811. DOI: http://dx.doi.org/10.1121/1.4933751.

[4] Qian-Jie Fu, Sherol Chinchilla, and John J. Galvin. "The role of spectral and temporal cues in voice gender discrimination by normal-hearing listeners and cochlear implant users". In: *The Journal of the Association for Research in Otolaryngology* 5.3 (2004), pp. 253–260. DOI: 10.1007/s10162-004-4046-1.

[5] James M. Hillenbrand and Michael J. Clark. "The role of F0 and formant frequencies in distinguishing the voices of men and women". In: *Attention, Perception, & Psychophysics* 71 (2009), pp. 1150–1166. DOI: 10.3758/APP.71.5.1150.

[6] Hideki Kawahara. "STRAIGHT, exploitation of the other aspect of VOCODER: Perceptually isomorphic decomposition of speech sounds". In: *Acoustical Science and Technology* 27.6 (2006), pp. 349–353.

[7] Damir Kovacic and Evan Balaban. "Voice gender perception by cochlear implantees". In: *The Journal of the Acoustical Society of America* 126 (2009), pp. 762–775. DOI: 10.1121/1.3158855.

[8] Tianhao Li and Qian-Jie Fu. "Voice gender discrimination provides a measure of more than pitch-related perception in cochlear implant users". In: *International Journal of Audiology* 50 (2011), pp. 498–502.

[9] Verena G. Skuk and Stefan R. Schweinberger. "Influences of fundamental frequency, formant frequencies, aperiodicity, and spectrum level on the perception of voice gender". In: *Journal of Speech, Language, and Hearing Research* 57 (2014), pp. 285–296. DOI: 10.1044/1092-4388(2013/12-0314).

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