Compensatory and adaptive responses to real-time formant shifts in adults and children

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Introduction

Auditory feedback plays an important role in the production of speech sounds [1–4].

- Teaching signal for the acquisition and adaptation of speech motor programs.
- Guiding signal for the online control and correction of speech movements.
- Perturbation of auditory feedback during speech production elicits **a compensatory response** in the opposite direction.
- Sustained application of perturbation causes the speech motor system **to adapt** and modify its speech programs.
- Auditory perturbation experiments may help to **understand early development of auditory-motor integration**.

Previous research:

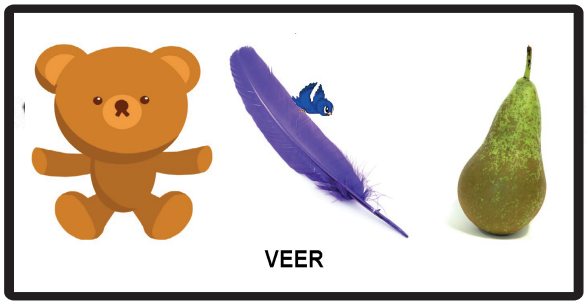
- Crucial steps are made in the development of auditory-motor integration around the age of 4 years.
- From this age on, children display similar compensation and adaptation characteristics as compared to adults [5, 6].
- Compensation and adaptation behaviour seems to stabilize with age [6, 7].
- However, token-to-token variability remains high.

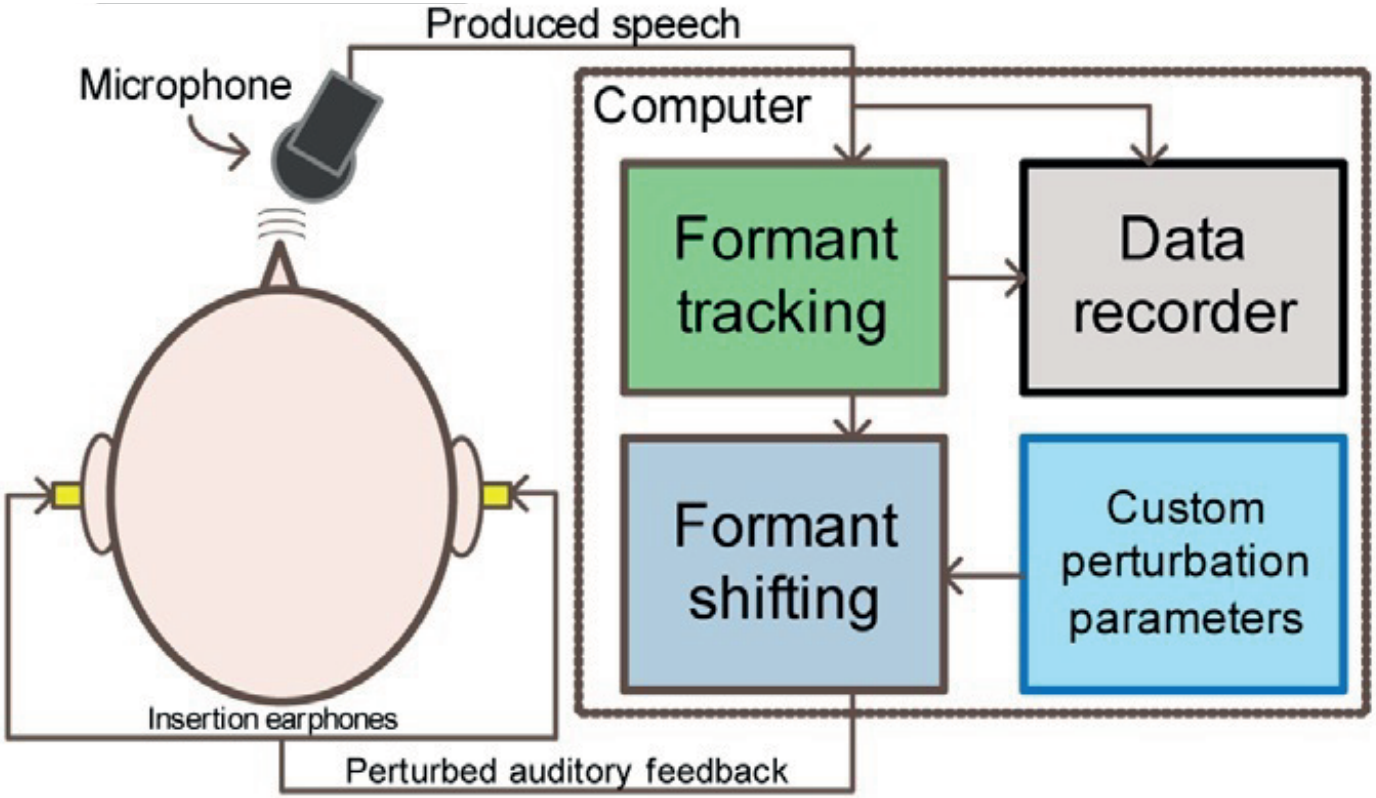
Research question:

- To what extent are native Dutch children able to compensate for and adapt to auditory feedback perturbation?

Experimental setup

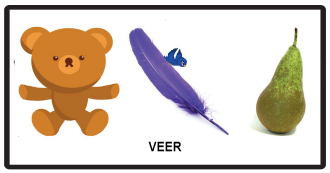
Real-time acoustic tracking and shifting of F1 and F2 using Matlab based software package Audapter [8].

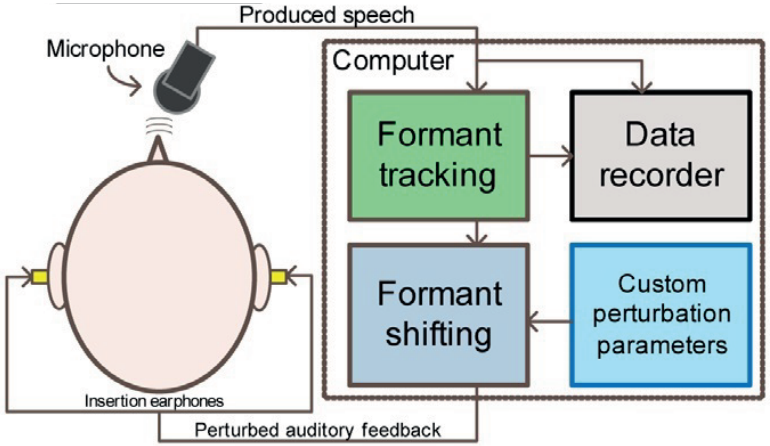




Experimental setup

Real-time acoustic tracking and shifting of F1 and F2.





- CVC words /be:r/ (bear), /ve:r/ (feather), /pe:r/ (pear).
- Participants were seated in front of a PC-monitor showing pictures of the target words.
- A bird flying over one of the pictures cued the participant to say the intended word.
- Perturbation: F1 raised 25%, F2 lowered 12.5%: /e:/ $\rightarrow$ /æ/.

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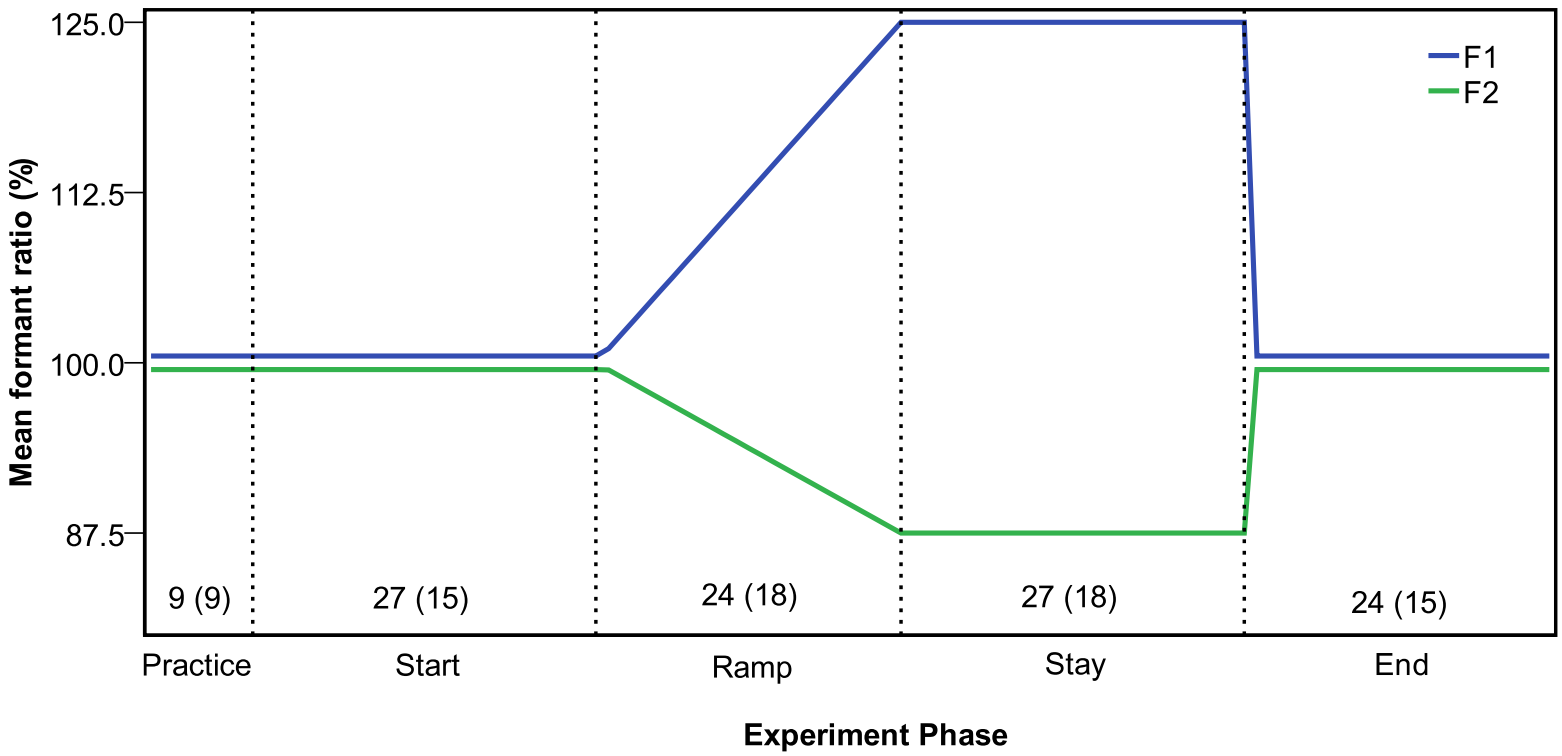
Perturbation paradigm



- Experiment length:
  - adults and children $>$ 7 y/o: 111 words
  - children $<$ 7 y/o: 75 words

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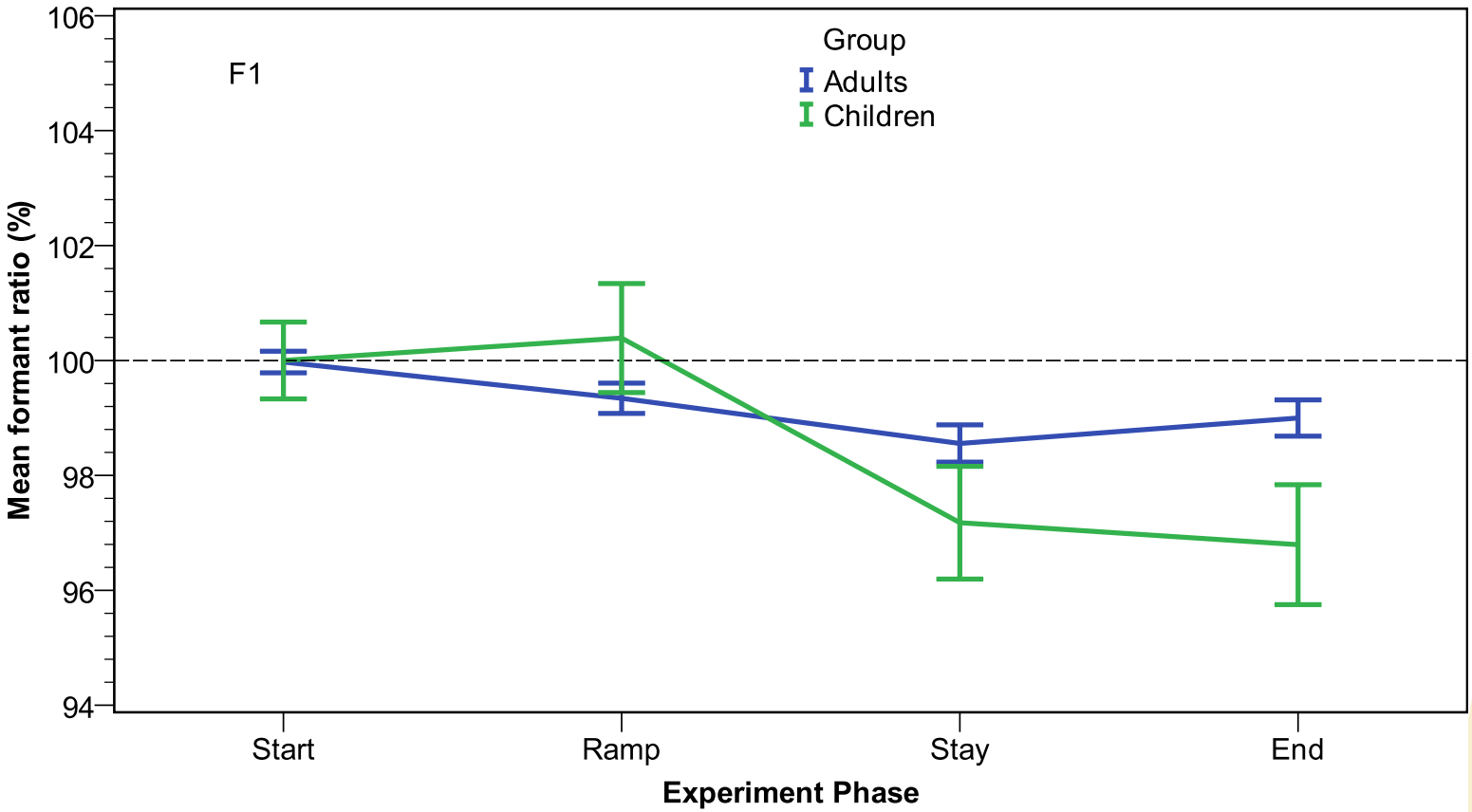
Participants

- 25 children (but 2 were unable to finish the experiment):
  - 11 female, 12 male
  - Age range: 4;0 - 8;7 y;m
  - Mean and SD: 5;7 (1;4) y;m
- 50 young adults:
  - 32 female, 18 male;
  - Age range: 18 - 29 years
  - Mean and SD: 22,3 (2,7) years

Analyses

- **Formants:** F1 and F2 measured from steady-state portions of vowels using PRAAT-scripts.
- **Compensation:** difference in normalized formant frequencies between the Start and Stay phase.
  A measure of motor control: the ability to notice and act on the mismatch between the motor command and the corresponding auditory result.
- **Adaptation:** differences in normalized formant frequencies between the Start and End phase.
  A measure of motor learning: the ability to update motor command representations.
- **Stability of compensation and adaptation:** token-to-token variability of first formant and second formant in the Start and End phase.
- **Statistics:** Linear Mixed Model analyses; fixed factors Group and Phase; random factor Subject, repeated factors Phase, Word, Repetition.

Results: compensation and adaptation for F1



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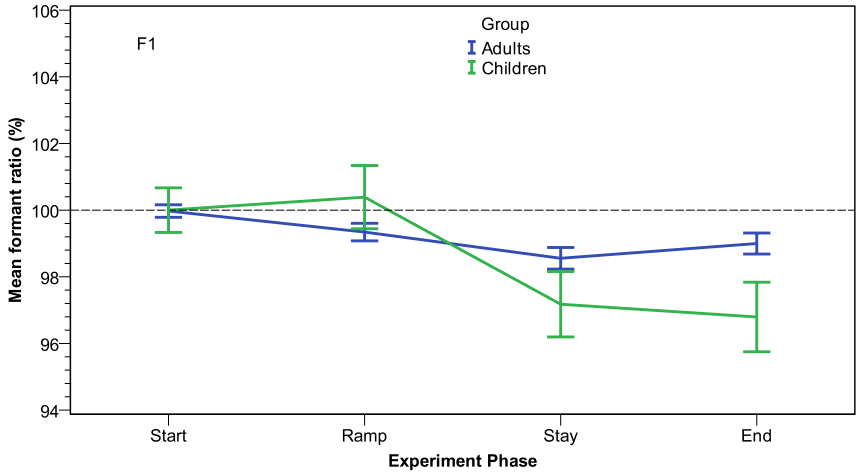
Compensation and adaptation effects for F1



- Linear Mixed Model results:
  - Group: $F(1,4061) = 36.5$, $p < .001 \Longrightarrow$ Children $>$ Adults
  - Phase: $F(2,3110) = 59.0$, $p < .001 \Longrightarrow$ Stay, End $>$ Start
  - Group * Phase: $F(2,3110) = 12.0$, $p < .001$
    - Start: no group differences
    - Stay: Children $>$ Adults
    - End: Children $>$ Adults
- Both groups showed compensation and adaptation effects.
- Effects of Children stronger compared to Adults.

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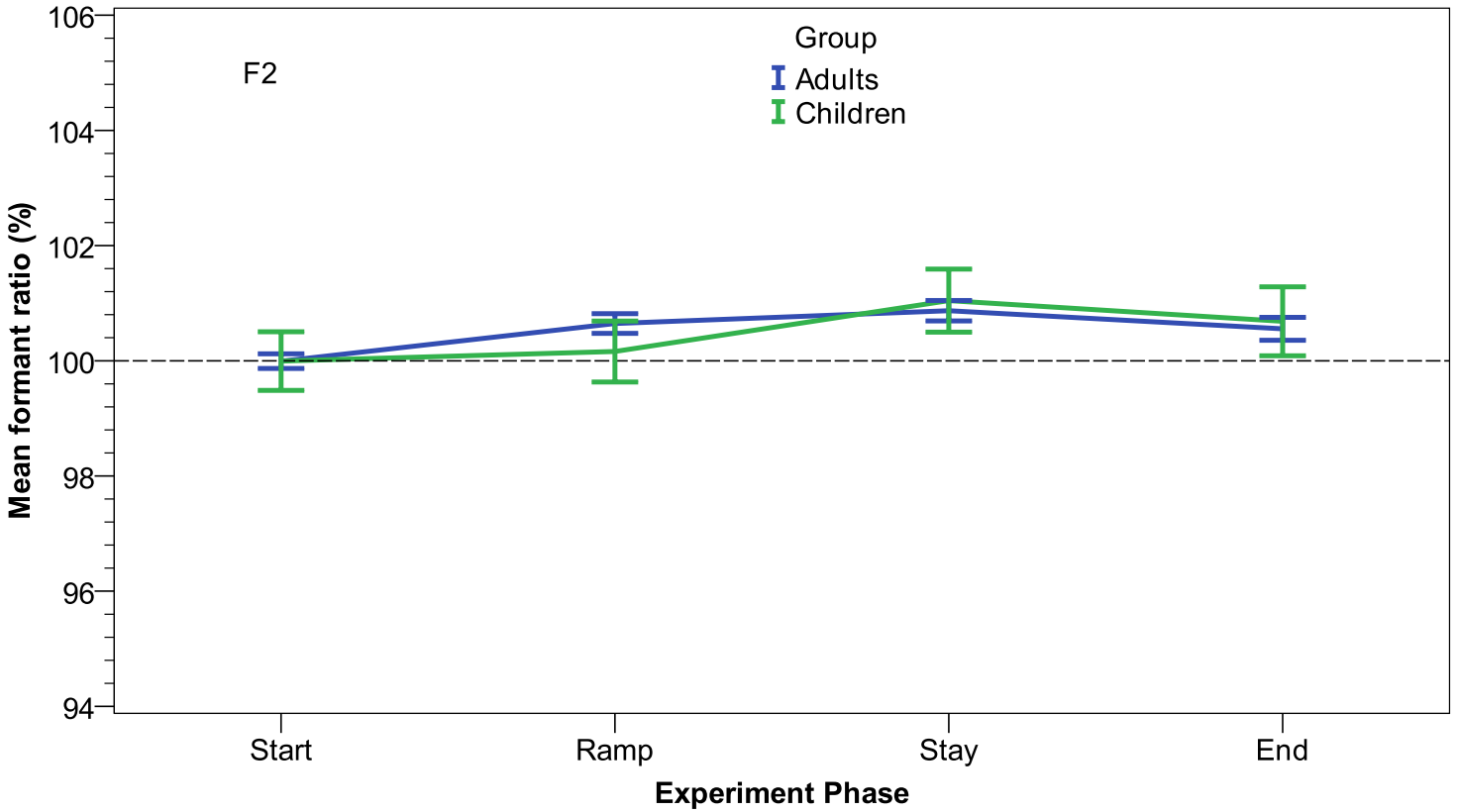
Compensation and adaptation effects for F2



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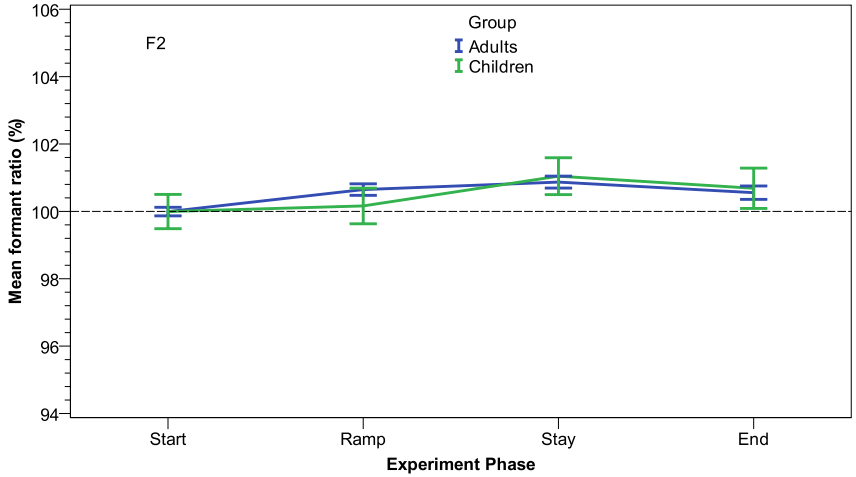
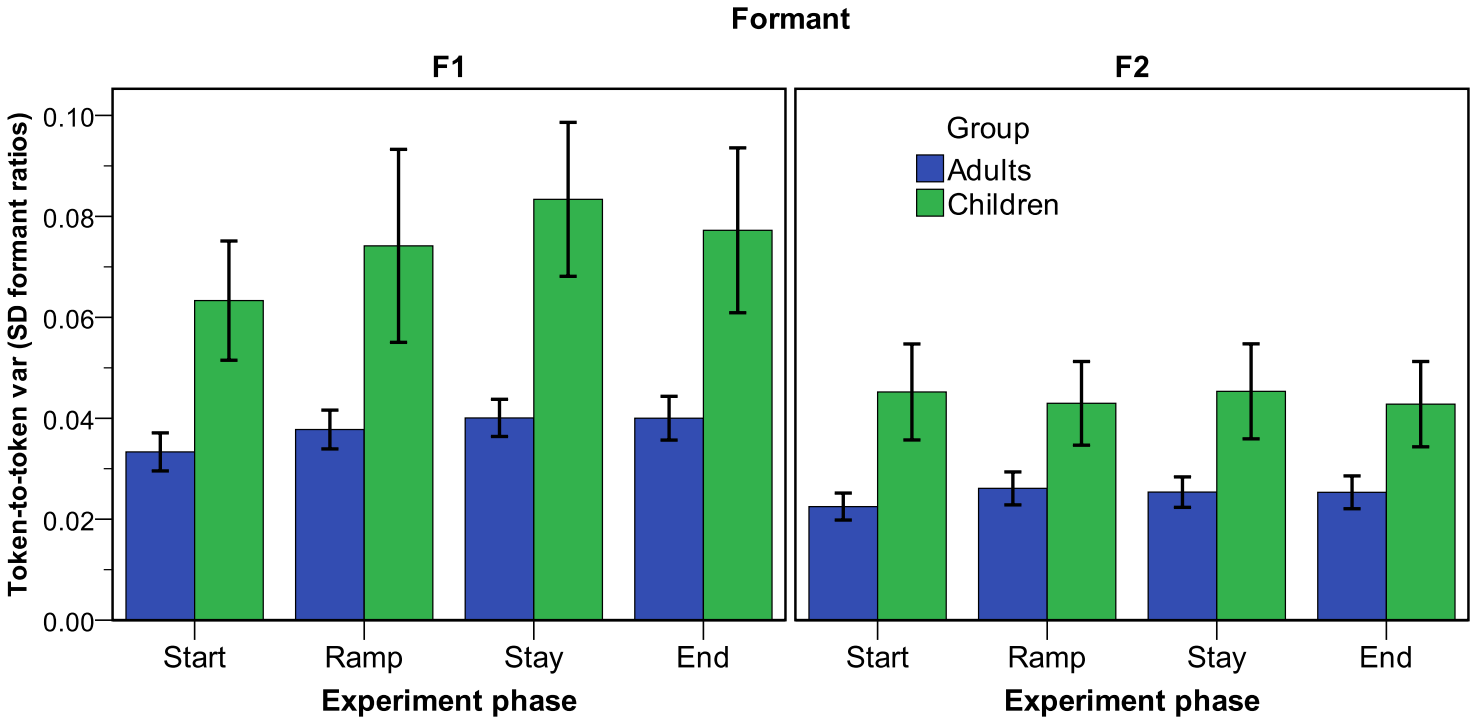
Compensation and adaptation effects for F2



- Linear Mixed Model results:
  - Group: $F(1,4168) = 3.6$, $p = .059 \Longrightarrow$ Children $\approx$ Adults
  - Phase: $F(2,3133) = 23.7$, $p < .001$
    - Stay, End $>$ Start
    - Stay $>$ End
  - Group * Phase: $F(2,3133) = .132$, $p = .877$
    - Across all phases: no group differences
    - Adults: Stay, End $>$ Start; Stay $>$ End
    - Children: Stay $>$ Start
- Adults showed compensation and adaptation effects.
- Children only compensation effects.

Token - to - token variability



- LMM first formant results:
  - Group: $F(2,292) = 80.1$, $p < .001 \Longrightarrow$ Children $>$ Adults
  - Phase: $F(3,292) = 3.9$, $p = .009 \Longrightarrow$ Stay $>$ Start
  - Group * Phase: $F(2,292) = .891$, $p = .446$
- LMM second formant results:
  - Group: $F(2,292) = 56.6$, $p < .001 \Longrightarrow$ Children $>$ Adults
  - Phase: $F(3,292) = .127$, $p = .944$
  - Group * Phase: $F(2,292) = .521$, $p = .668$

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Discussion: group comparisons

- Experiment length adequate to induce short-term training and learning.
- Compensation stronger for Children compared to Adults.
- Auditory-motor properties less ingrained in Children.
- Adaptation stronger for Children compared to Adults.
- Adults revert faster to ingrained, original representation of the speech sounds.
- Stronger effects in Children possibly due to larger formant vowel space [9].

Discussion: group comparisons

- Overall effect of perturbation F1: $\sim$ 8.4 %; F2: $\sim$ 5.6 %.
- Adjusting jaw opening (F1 movement) is easier compared to changing tongue shape (F2 movement).
- Or effect of F2 perturbation not strong enough (12.5%).
- Large within-group variability in Children might result from different control strategies:
  auditory feedback vs somatosensory feedback trade-off [10].
- This feedback trade-off might change over time, and stabilise with age.

Discussion: token-to-token variability

- Token-to-token variability in F1 and F2 higher in Children.
- Variability not disproportionally larger for Children during stay or end phase.
- Added challenge of perturbed auditory feedback to auditory-motor integration does not influence variability.
- In this paradigm increased token-to-token variability possibly an artefact of measuring formants in children's speech.
- Caution when using token-to-token variability as outcome measure.

Acknowledgements

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- Participant recruitment by Anniek van Doornik-van der Zee and Margoke Nijssen.
- Audapter software by Shanqing Cai.

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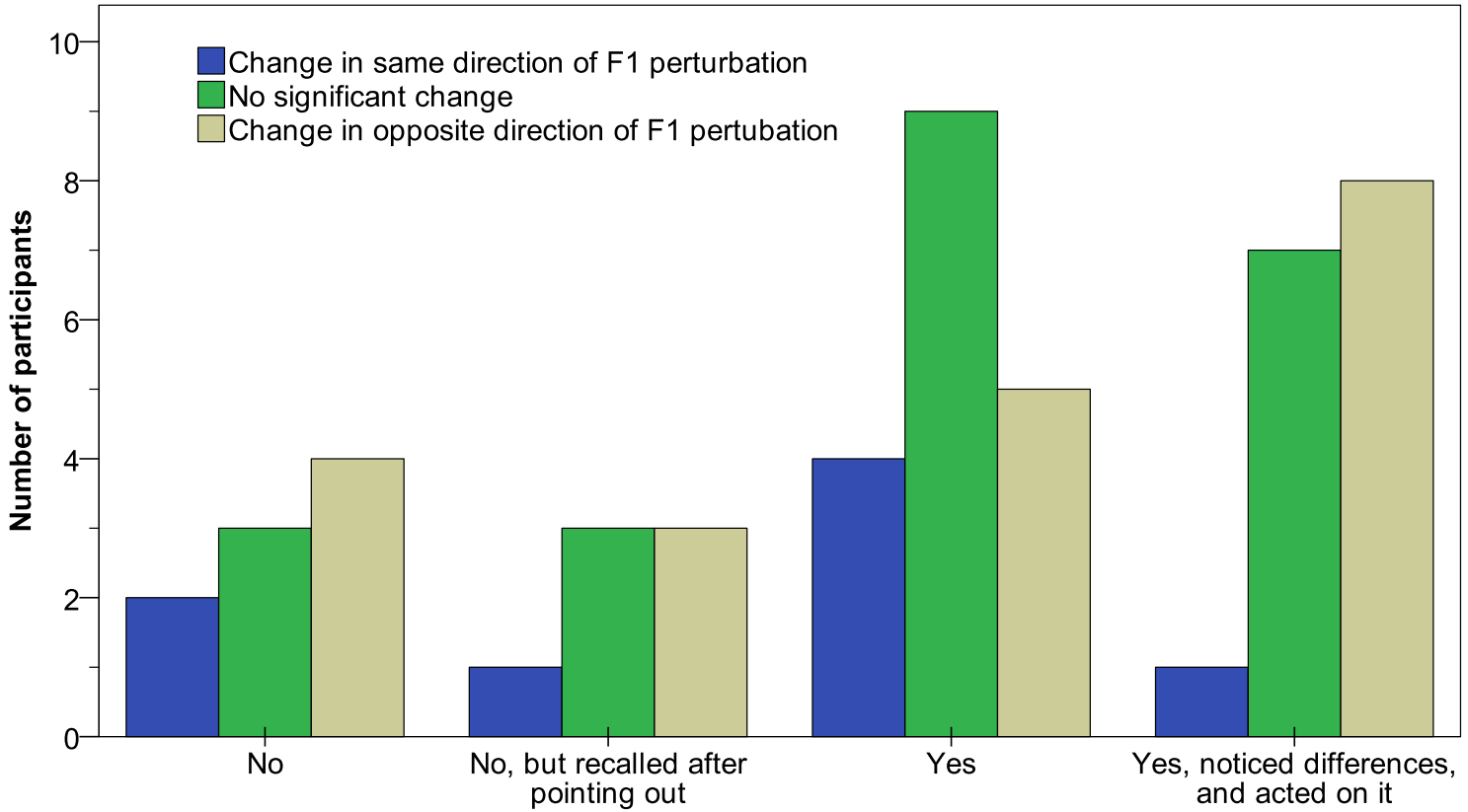
Experiment debriefing

- Previous studies reported participants did not notice perturbations when explicitly asked afterwards[4, 11].
- During pilot: participants spontaneously indicated to hear voice manipulations.
- Does this have an effect on perturbation characteristics?
- Experiment debriefing young adults:"*Did you hear something odd when listening to your own voice*?"
- Four response types:
  - No.
  - No, but recalled after pointing out during debriefing.
  - Yes.
  - Yes, and acted on it (usually trying to correct).
- For each AD analysed whether they showed (I) **a significant perturbation effect** and (II) whether it was in the **expected direction**.

Results debriefing: responses for F1



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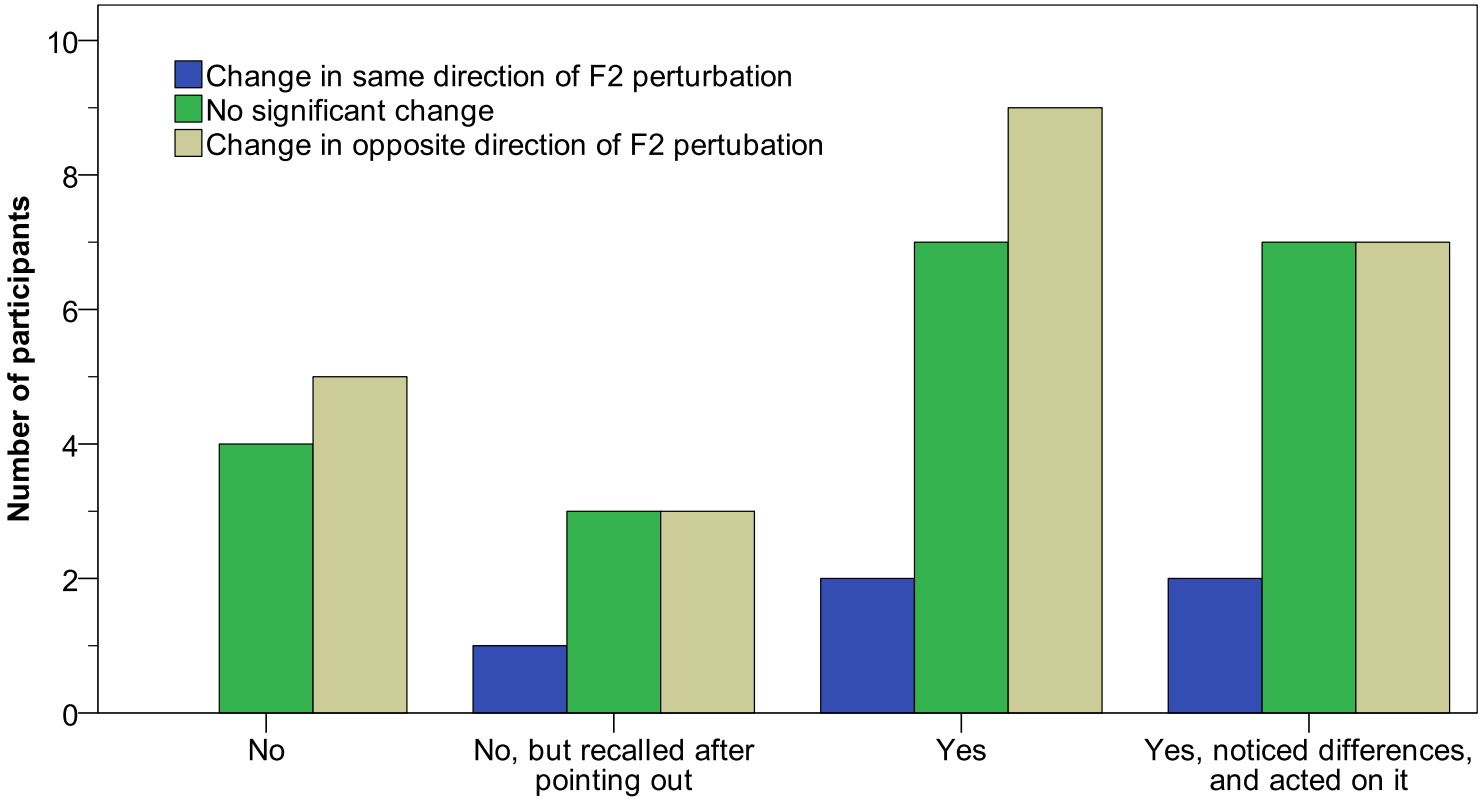
Results debriefing: responses for F2



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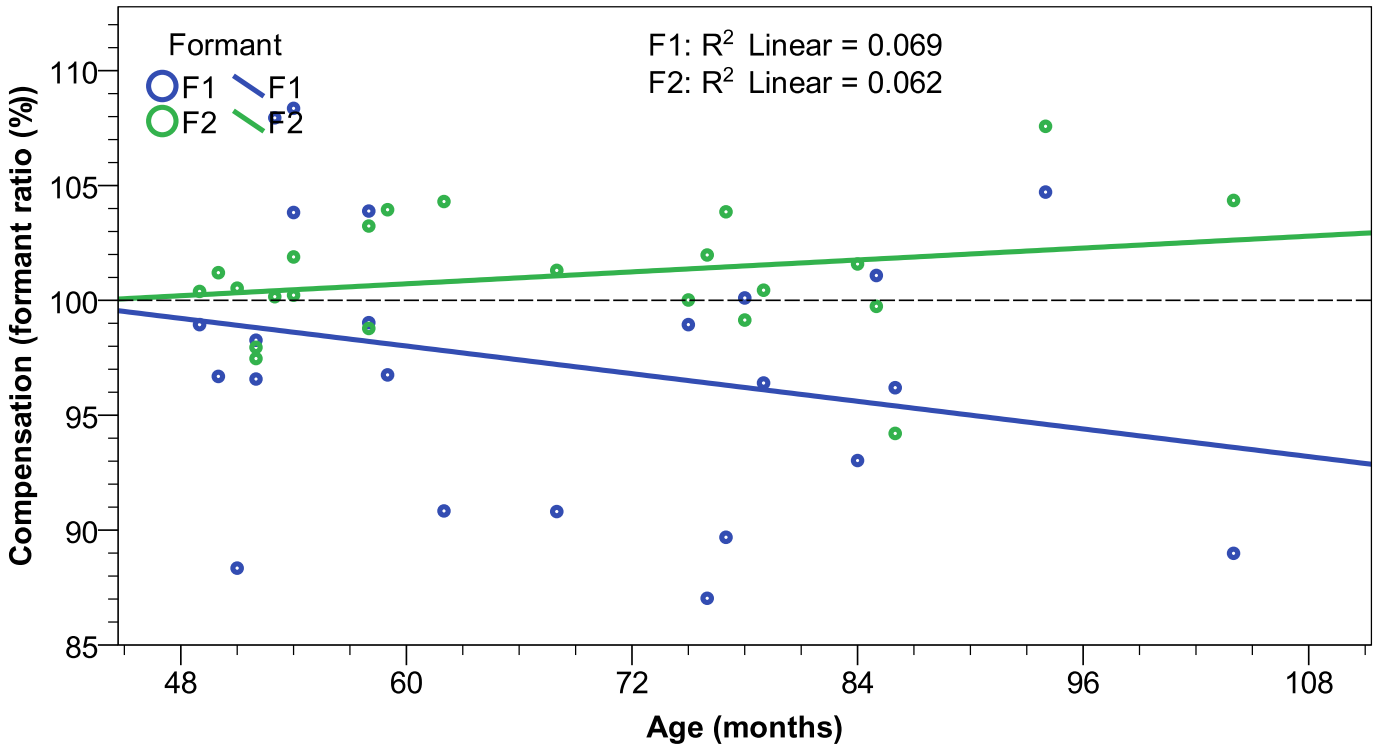
Discussion: debriefing results

- Overtly noticing stimuli manipulations does not entail different adaptation and compensation strategies.
- Deliberately 'battling' manipulations was not successful.
- Subconscious compensation and adaptation effects during experiment were strong and sustainable.

Developmental changes: compensation responses



- Compensation strength increases with age, but not significantly.

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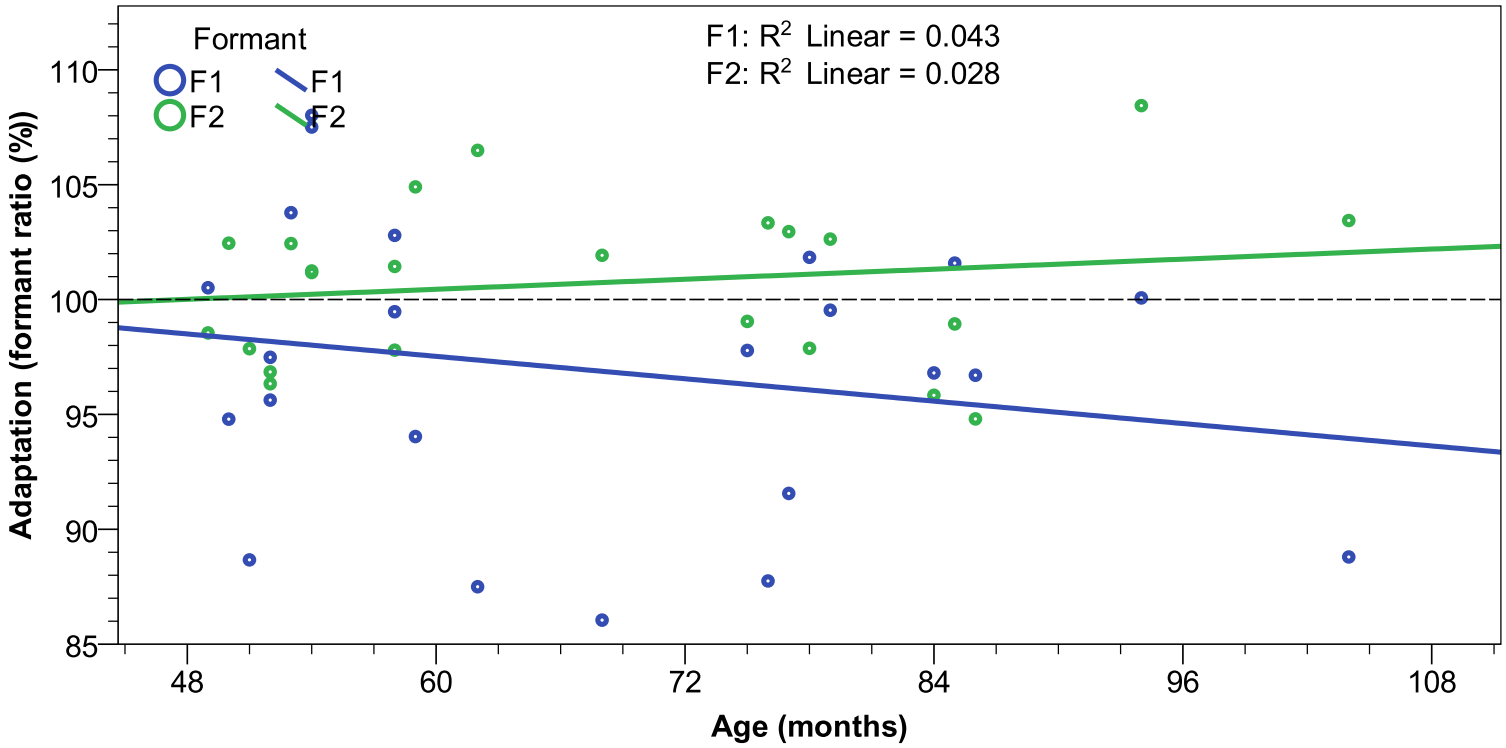
Developmental changes: adaptation responses



- Adaptation strength increases with age, but not significantly.

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Discussion: Developmental effects

- No linear correlation of age with compensatory and adaptive responses.
- Learning strategies do not change significantly in age span 4-9 years.
- ...or auditory feedback perturbation paradigm unable to capture process.

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