

¹ Holland Bloorview Kids Rehabilitation Hospital; ² Institute of Biomaterials and Biomedical Engineering, University of Toronto; ³ Rehabilitation Sciences Institute, University of Toronto; ⁴ Department of Speech Language Pathology, University of Toronto

Introduction

- Auditory feedback informs our correct production of speech.
- By analyzing children's speech production under experimentally altered auditory feedback, we can learn how it is involved in the maturing speech motor control system.
- A structured review methodology has not been applied to explore the use of these methods in research with children and youth.

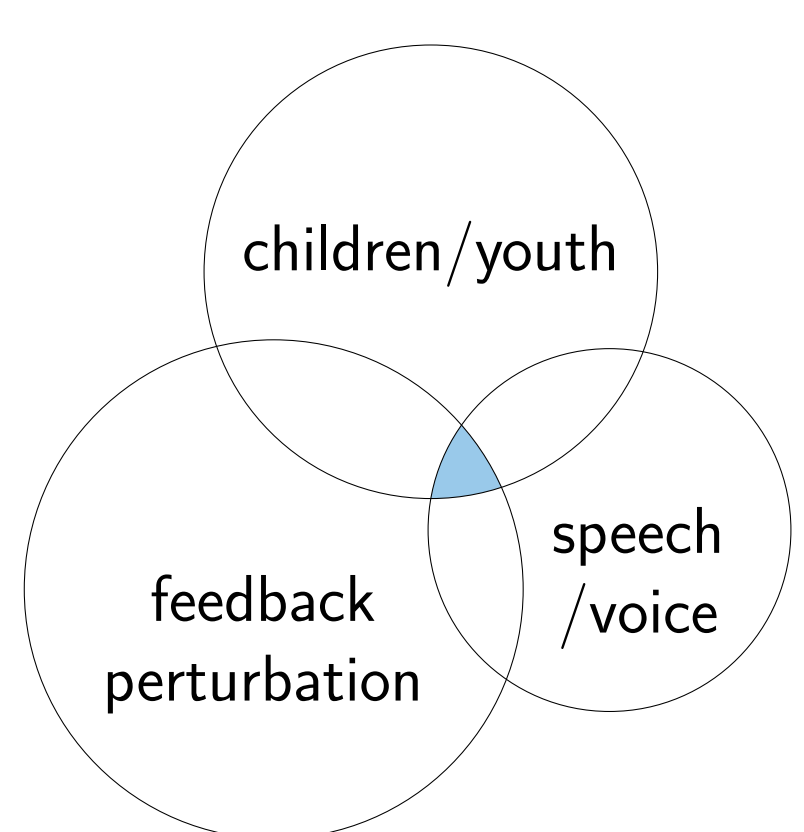
Objectives

This scoping review explores the use of altered auditory feedback as a methodological approach in speech production research with children/youth. We aim to:

- 1 identify common research questions and synthesize the findings
- 2 characterize the participants involved in this research
- 3 highlight future directions for these methodologies.

Methods

- Our scoping review follows the structured framework presented by Arksey and O'Malley [1] and further developed by Levac et al.[2].
- We conducted our search in Medline, Embase, PsycINFO, and Web of Science, using keyword and MeSH terms from the categories depicted in Figure 1.
- Select inclusion/exclusion criteria are highlighted in Fig. 1.



- ✓ Real-time perturbations of auditory feedback
- ✓ Analysis of immediate effects on speech
- ✓ Typically-developing and clinical participants
- ✗ Speech production not targeted
- ✗ Analysis of long-term intervention effects
- ✗ Not an experimental study (e.g. commentaries)

Figure 1: The search focus (blue) and inclusion/exclusion criteria.

Results

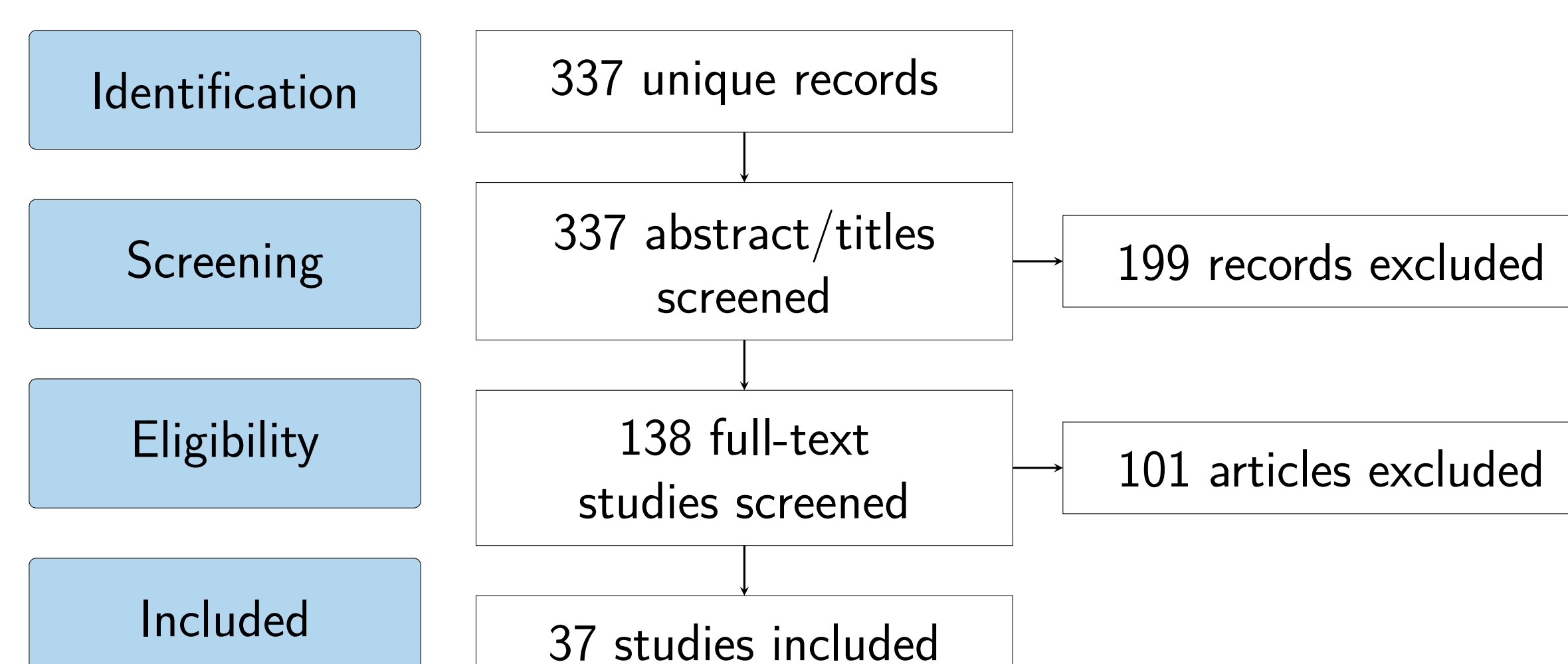


Figure 2: PRISMA chart of the scoping review process.

- Precise frequency-domain manipulations of auditory feedback have emerged in the last 30 years, while studies before 1999 explored time-domain delays and sidetone masking.

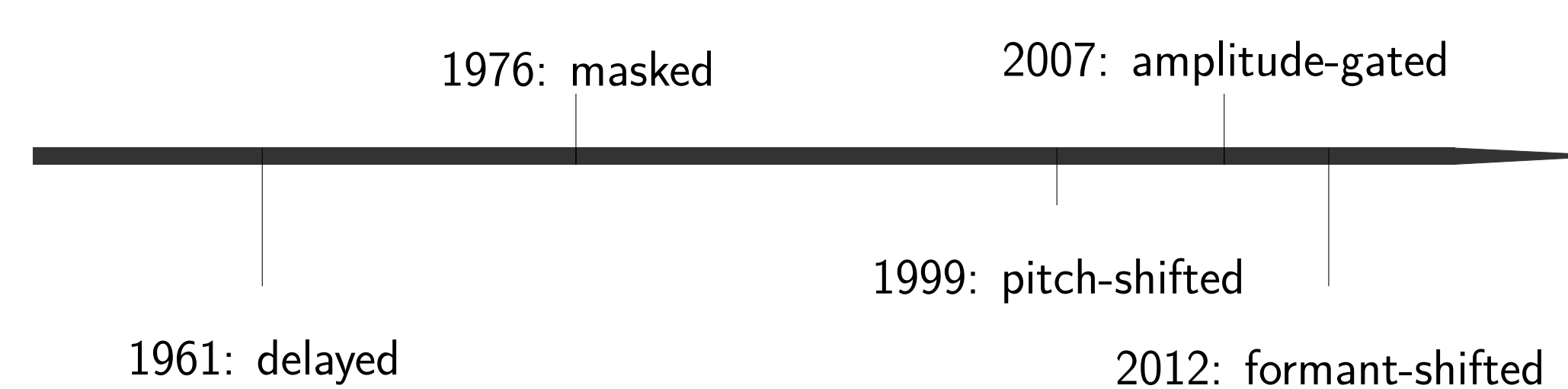


Figure 3: A timeline of the first publication for each perturbation modality.

- Some common aims of the literature are to understand:
 - How children in different age groups respond to perturbations ($N = 11$)
 - How children and adults respond differently to perturbations ($N = 13$)
 - How auditory feedback is implicated in clinical populations ($N = 13$)
 - The effect of perturbation on fluency in clinical populations ($N = 9$).

- Fig. 4 summarizes the perturbation modalities in this literature:

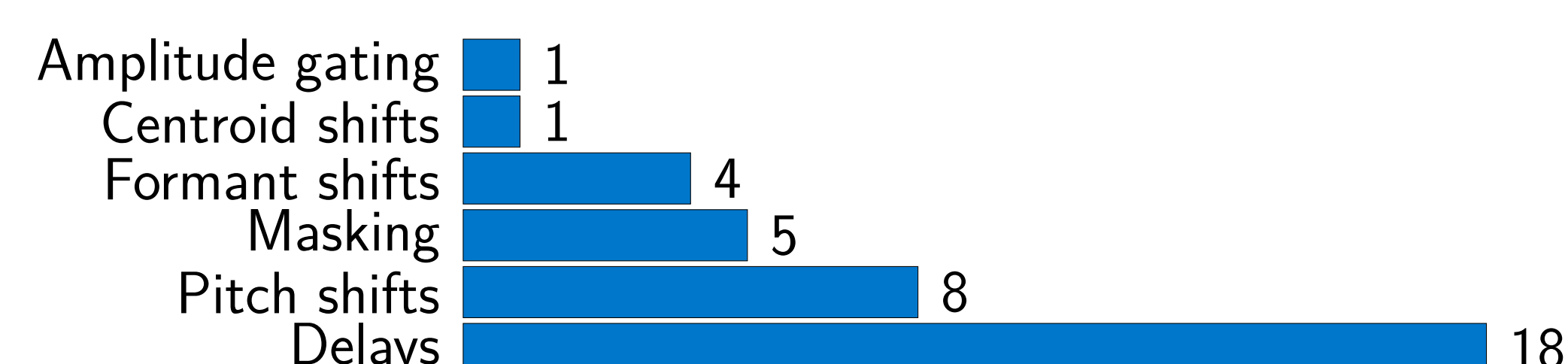


Figure 4: Perturbation modalities represented in the reviewed studies.

- Summaries and highlights of research in delayed, pitch-shifted, and formant-shifted feedback are presented below.

Results (continued)

- Most research is conducted in typically-developing children aged 7 to 9 or in children who stutter aged 9 to 11 (Table 1).

Table 1: A count of the number of studies involving children/youth by age.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
TD	2	5	4	9	8	12	15	15	13	13	11	9	7	6	5	4	4	2
CWS					2	4	5	4	7	7	7	5	5	2	2	1	1	1
OTH					2	2	4	5	5	5	5	3	2	2	2	2	2	

TD = typically-developing. CWS = children who stutter. OTH = all other clinical diagnoses (auditory processing disorders $N = 1$, autism spectrum disorders $N = 1$, childhood apraxia of speech $N = 1$, children who are deaf $N = 1$, speech sound disorders $N = 1$, children with speech delay $N = 1$).

Conclusions and future directions

- Combined, the research suggests that:
 - Children respond to different types of perturbations in different ways.
 - The magnitude of perturbation can impact the strength of response.
 - The development of auditory feedback monitoring is not yet clear, but it appears that this system is not fully mature in children below the age of 12.
 - Children who stutter may speak more fluently under delayed feedback.
- Future directions for this work may include:
 - Exploring the role of auditory feedback in the development of speech across larger samples of children in narrower age ranges.
 - Comparing the effects of multiple perturbations in the same participants.
 - Developing age-appropriate methods to explore speech development in the critical speech development stages of 1 to 4 years old.

References

- [1] H. Arksey and L. O'Malley, "Scoping studies: towards a methodological framework," *Int J Soc Res Methodol*, vol. 8, pp. 19–32, Feb. 2005.
- [2] D. L. et al., "Scoping studies: advancing the methodology," *Implement Sci*, vol. 5, p. 1, Sept. 2010.

Acknowledgements

- Pui-Ying Wong, research librarian
- Funding: Natural Sciences and Engineering Research Council of Canada, Wildcat Voyager Scholarship

Results in depth: Summary tables for delayed, pitch-shifted, and formant-shifted feedback research

Delayed auditory feedback ($N = 18$)

Feedback manipulations	
8	Multiple delays
8	200-ms delay only
2	Other delays (250-ms delay only; 630-ms delay only)
Measures	
16	Speech rate/timing changes
15	Dysfluency count/dysfluency rate
4	Sound pressure level
Result highlights	
5	Younger participants more affected than older participants
1	Older participants more affected than younger participants
6	Effects are delay-dependent
3	Delays impact the fluency of clinical groups

Pitch-shifted auditory feedback ($N = 8$)

Feedback manipulations	
2	Multiple F_0 shifts
4	Downward 100-cent shift of F_0 only
2	Upward half-octave shift of F_0 only
Measures	
1	Speech rate/timing changes
1	Dysfluency count/dysfluency rate
6	Magnitude of F_0 changes
5	Latency of F_0 changes
Result highlights	
2	Larger F_0 compensatory shift in older than younger participants
1	Larger F_0 compensatory shift in younger than older participants
1	Increased fluency in children who stutter

Formant-shifted auditory feedback ($N = 4$)

Feedback manipulations	
1	Raise F_1 by 200 Hz, lower F_2 by 200 Hz
1	Raise F_1 by 25%
2	Raise F_1 by 25% Hz, lower F_2 by 12.5% Hz
Measures	
4	Magnitude of formant changes
Result highlights	
1	Children under 4 do not compensate for perturbed formants
1	Below the age of 12, children's compensatory responses are not fully adult-like
1	Children who stutter respond similarly to children who do not
1	Children with speech sound disorders have limited ability to compensate, compared to typically-developing peers