

# Development of coarticulation in Greek consonant clusters: Psychoacoustic data



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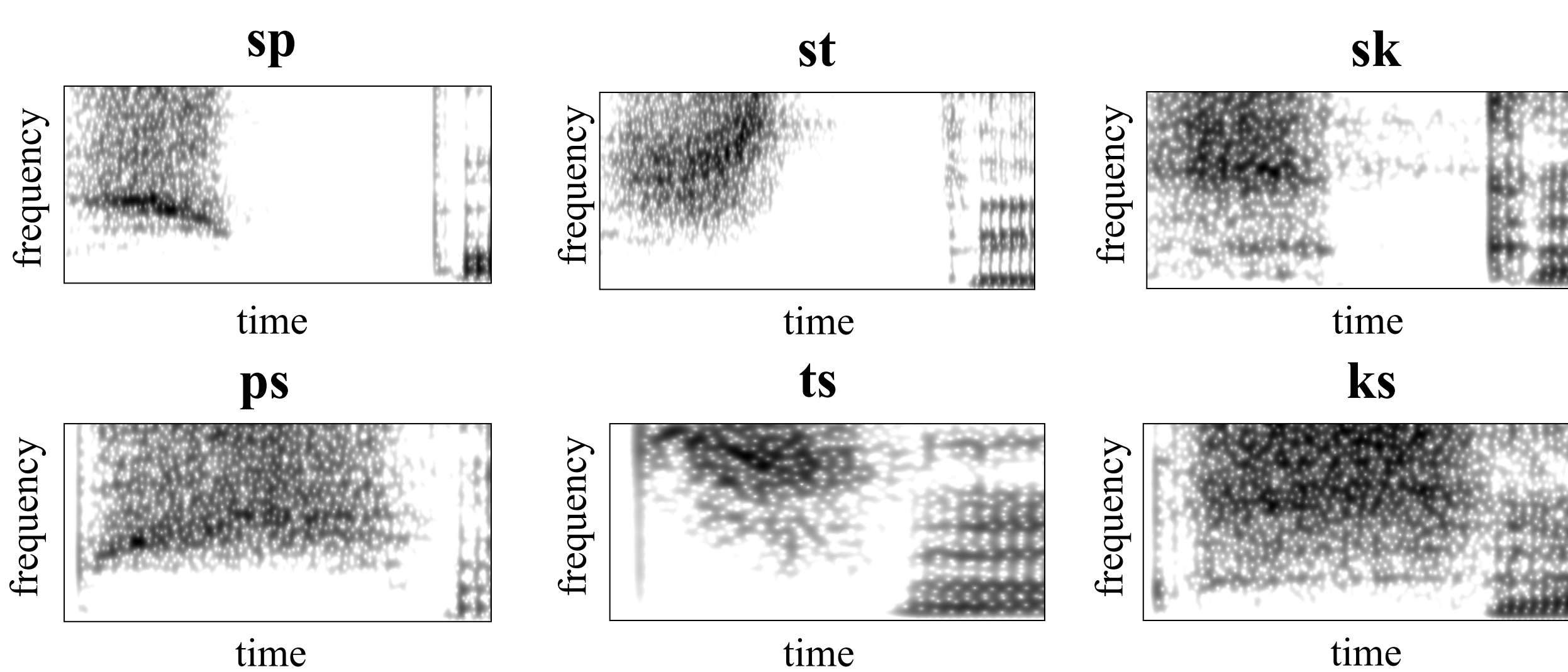
## INTRODUCTION

- *Coarticulation* refers to the fact that speech sounds are modified by the influence of contiguous sounds.
- Most studies of coarticulation have looked at the effects of a vowel on a consonant or vice-versa.
  - Considerably less is known about consonant-to-consonant coarticulation patterns in consonant clusters.
- Another gap in our knowledge about coarticulation concerns the development of coarticulation in children.
  - Previous studies have reported conflicting results, with some reporting that children coarticulate more than adults (e.g., Nittrouer et al., 1996), and others that they coarticulate less (e.g., Kent, 1983).
  - A third set of findings indicates that children and adults show similar patterns of coarticulation in their speech, but that children's patterns are generally more variable than those of the adults (e.g., Katz et al., 1991; Munson, 2004).
    - These divergent findings are likely due to differences in the methods used and the sounds studied.

## STUDY AIMS

- To look at the effects of stop place of articulation on contiguous [s] in Greek word-initial /s/-stop and stop-/s/ clusters, using dynamic psychoacoustic measures.
- To compare the adult productions to those of 2-to 5-year-old Greek children to describe developmental patterns.

## ACOUSTIC CUES TO STOP PLACE OF ARTICULATION



- The energy concentration for /s/ changes depending on adjacent stop consonant:
  - Downward direction before /p/
  - Upward direction before /t/
  - Straight direction before /k/
- 'Mirror' image of /s/-stop clusters:
  - Upward direction after /p/
  - Downward direction after /t/
  - Straight direction after /k/

## METHODS

### [Participants]

- Sixty typically-developing 2-to 5-year-old Greek children and twenty adults.
- Participants in a larger project on cross-linguistic phonological development.
- Passed a hearing screening using otoacoustic emissions prior to testing.

### [Stimuli]

- Consonant sequences /sp/, /st/, /sk/, /ps/, /ts/, /ks/ placed in word-initial position in familiar real words before front (/i/, /e/) and non-front vowels (/a/, /o/, /u/).
- Correct productions and substitutions that contained a fricative were analyzed.

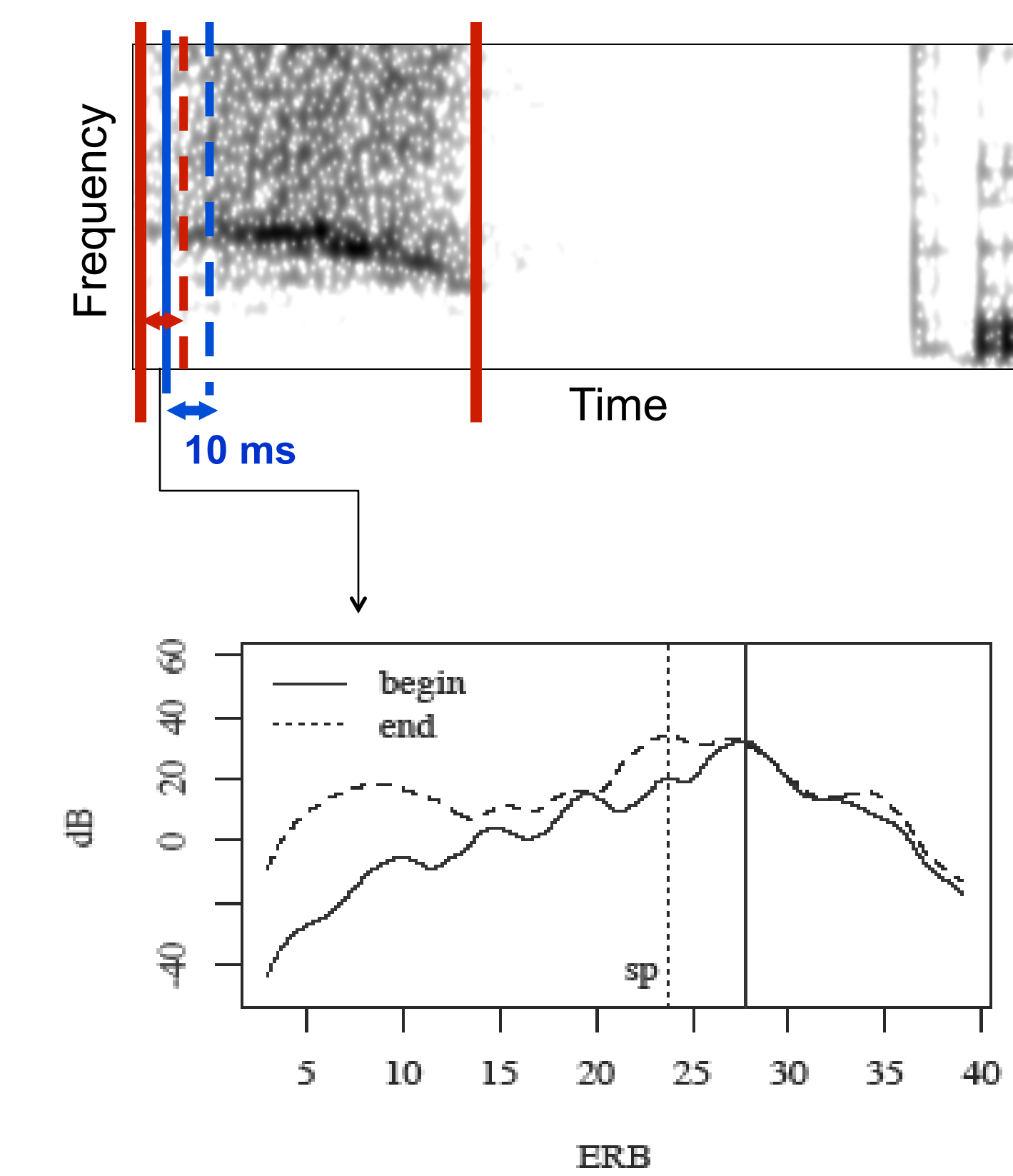
### [Procedure]

- A picture and a digitized recording of the stimulus were presented simultaneously.
- Participants were instructed to repeat each word as they heard it.

### [Psychoacoustic analysis]

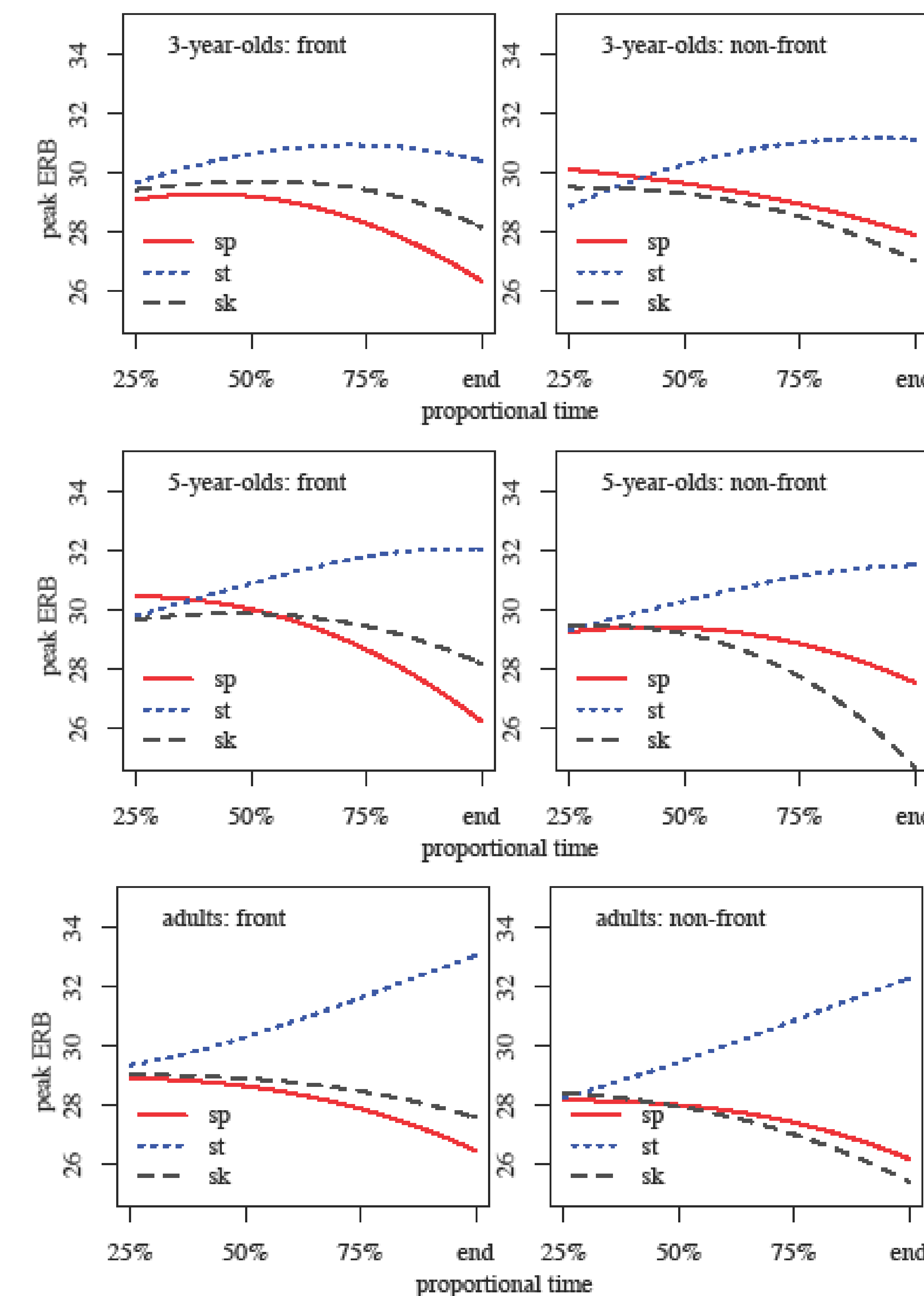
- A series of 10 ms slices (with 5 ms overlap) was generated from the beginning to the end of frication noise and extracted smoothed by a Hanning window.
- These 10 ms slices were then used to calculate the highest amplitude frequency (peak ERB) in the specific loudness by equivalent rectangular bandwidth (ERB) spectrum for each slice.
- **Peak ERB:**
  - The frequency of the loudest peak in the sonex by ERB spectrum (Moore et al., 1997)
  - Psychoacoustic analogue to the peak frequency

## ILLUSTRATION OF MEASUREMENT PROCEDURE



### Results: /s/-stop clusters

Peak ERB trajectories of /s/-stop sequences produced by 3-year-olds (top), 5-year-olds (middle), and adults (bottom), as estimated by the mixed-effects models.

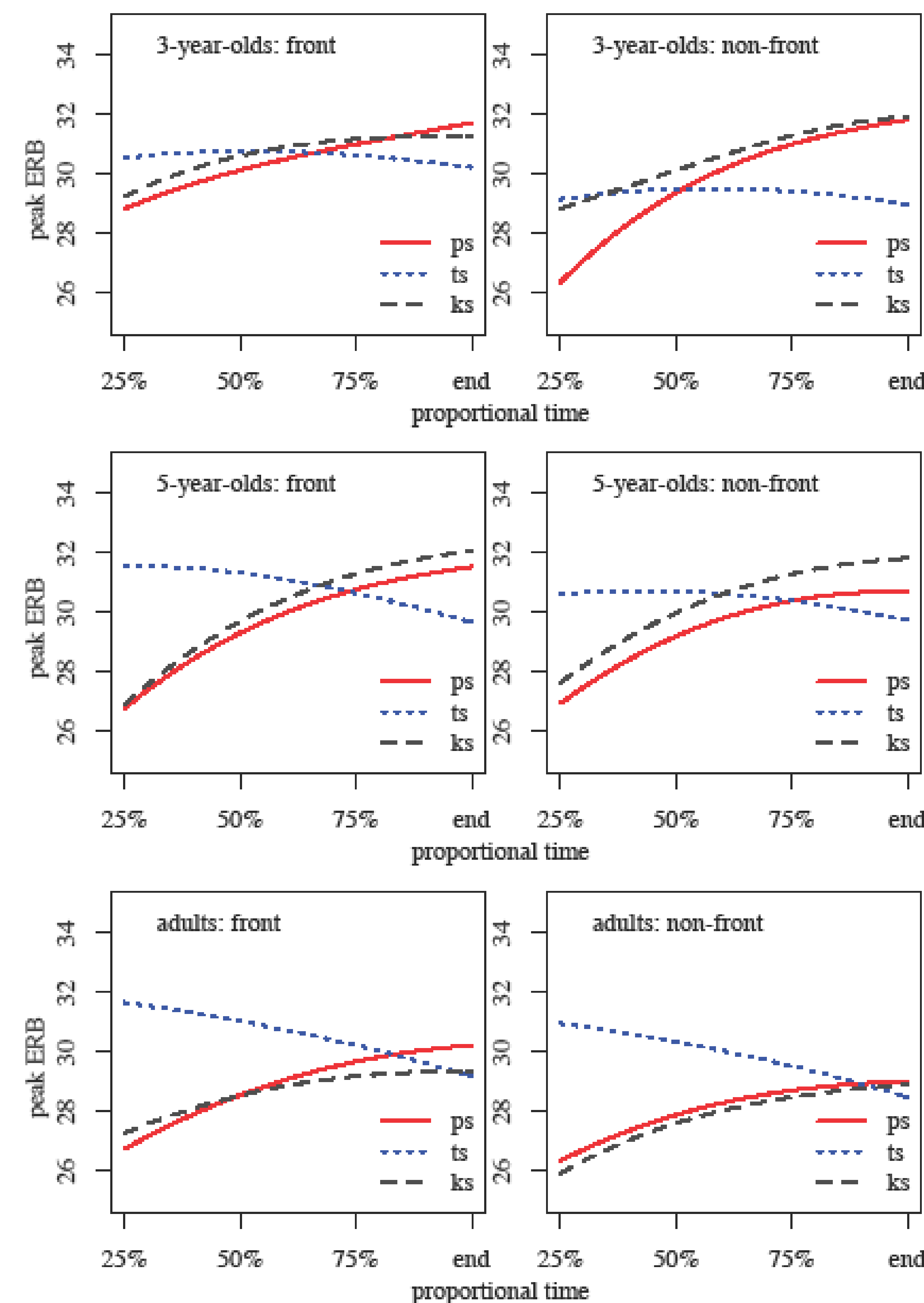


## STATISTICAL ANALYSIS

- The peak ERB trajectories of the tokens were adjusted to have the same number of data frames by taking the peak ERB value of each token at four proportional locations:
  - /s/-stop sequences: 25%, 50%, 75% and endpoint
  - stop-/s/ sequences: Beginning point, 25%, 50%, 75%
- Mixed-effects regression models were built separately for each cluster, vowel (front vs. non-front) and age group to examine stop place of articulation effects on fricative trajectories.
- In each model, the DV (normalized peak ERB values) was explained by the factor of time.
- Orthogonal polynomial parameters up to the third order (linear, quadratic, cubic) were added to each model as fixed effects to capture a wide array of complex patterns of change over time.
  - **Linear** term: describes the constant rate of change of the curve per unit time (the slope)
  - **Quadratic** term: describes the instantaneous rate of change of the curve (whether the curve is concave or convex to the x-axis)
  - **Cubic** term: describes the asymmetry of the curve (its peaks and valleys)
- The sign and magnitude of the coefficients of the three terms describe the direction and rate of excursion in the curve (Barr, 2008; Mirman, Aslin, & Magnuson, 2007).
- Both the intercept and the slope were allowed to vary at the individual token and speaker level.
- Deviance statistics was used to compare model fit (Singer & Willett, 2003).

### Results: stop-/s/ clusters

Peak ERB trajectories of stop-/s/ sequences produced by 3-year-olds (top), 5-year-olds (middle), and adults (bottom), as estimated by the mixed-effects models.



## SUMMARY OF RESULTS

- **Adults:**
  - Consistent separation between the trajectories for sequences containing /p/ and /t/ (at the end of the trajectory for /s/-stop sequences and at the beginning of the trajectory for stop-/s/ sequences), with low values for the part of the trajectory closest to /p/ and high values for the part of the trajectory closest to /t/.
  - The trajectories for the sequences containing /k/ generally patterned with those of the sequences containing /p/, but were more variable across vowel contexts and less steep.
- **Children:**
  - The trajectories of the fitted curves for the 3- and 5-year-olds were generally similar in shape to those of the adults, but more variable.
  - The separation between the trajectories for the sequences containing /p/ and /t/ increased from age 3 to age 5 to adults.
  - The slope of the trajectories also generally increased with age, particularly in the case of /ts/.
  - The trajectories for sequences containing /k/ generally patterned with sequences containing /p/, but were even more variable than those of the adults.

## DISCUSSION AND CONCLUSION

- Similar cues for stop place of articulation in adjacent [s] for both /s/-stop and stop-/s/ sequences.
- Results from mixed-effects models showed clear distinctions in peak ERB values for sequences containing /p/ and /t/ in productions of Greek adults.
- Specifically, /sp/ (and /ps/) were associated with lower peak ERB values towards the end (or the beginning) of the trajectory, while /st/ (and /ts/) were associated with higher peak ERB values toward the end (or the beginning) of the /s/ trajectory.
- Both /sk/ and /ks/ were less well-differentiated by peak ERB values than were sequences containing /p/ and /t/.
- Children's patterns were strikingly similar to those of the adults.
- However, as age decreased the trajectories of peak ERB values became more variable, and showed less separation between the different stop consonants.
  - Suggests children's production of [s] in /s/-stop and stop-/s/ clusters provided somewhat less information to the listeners about the place of articulation of the adjacent stop.
  - The sequence /ts/ had particularly less steep peak ERB trajectories as age decreased.
    - Suggests children were making a more back constriction (and thus had a longer front resonating cavity) for the [s] than did the adults.
    - The above is particularly interesting considering that /ts/ is one of the latest acquired sounds in Greek.
- Future work needs to examine additional measures (such as a measure of compactness) to describe coarticulation patterns in /sk/ and /ks/ clusters.
- A perception experiment should also be designed to test whether differences in peak ERB trajectories are perceived differently by adult native speakers.

## ACKNOWLEDGMENTS

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