Vowel-context effects on the spectral dynamics of English & Japanese sibilant fricatives

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Purpose

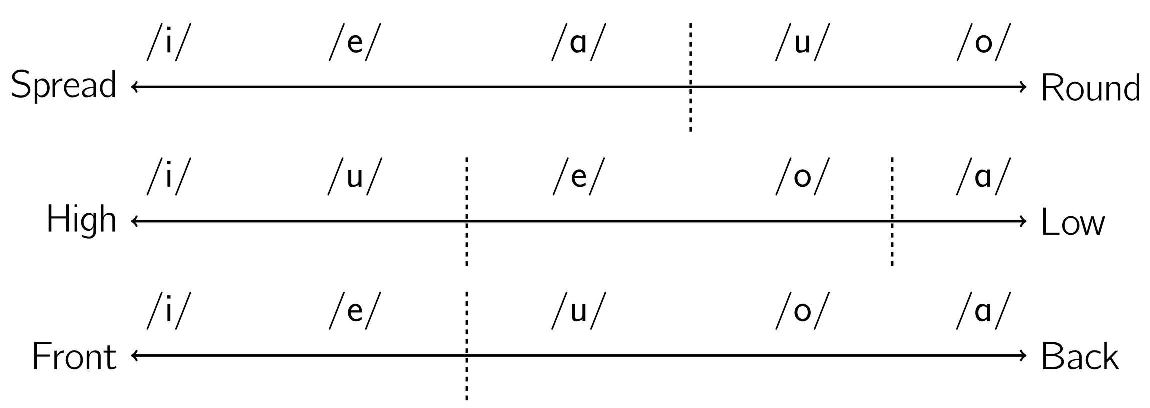
- ▷ Fluent speech requires the coproduction of neighboring speech sounds; thus, the acoustic properties of a speech sound are adapted to the context in which it is produced.
- ▷ Articulographic (Katz & Bharadwaj, 2001) and ultrasound (Zharkova et al., 2014) studies have found temporal coarticulatory effects of a following vowel on the trajectory of the tongue during the production of a sibilant.
- ▷ Anticipatory vowel-context effects on the spectral properties have been reported at discrete locations in the sibilant—e.g., near frication midpoint or vowel boundary (McGowan & Nittrouer, 1988).
- ▶ Spectral properties of sibilants vary temporally (Iskarous et al., 2011; Reidy, 2015); hence, the current study investigated effects of vowel context on the *spectral dynamics* of English /s/ and /ʃ/ and Japanese /s/ and /ɕ/.
- ▶ Two psychoacoustic spectral properties were considered: (1) *peak ERB_N-number*, a measure of the most prominent frequency; (2) *excitation drop*, a measure of spectral balance.

Background

Vowel features

- ▷ In English & Japanese, the vowels /i/, /u/, /e/, /o/, /ɑ/ exhibit language-specific placement along spread-round, high-low, and front-back continua (e.g., Japanese /u/ is relatively more spread than English /u/), but broadly follow the pattern shown in Fig. 1 (cf. Fromkin, 1964, Fukuda & Hiki, 1982; Wada et al., 1969).

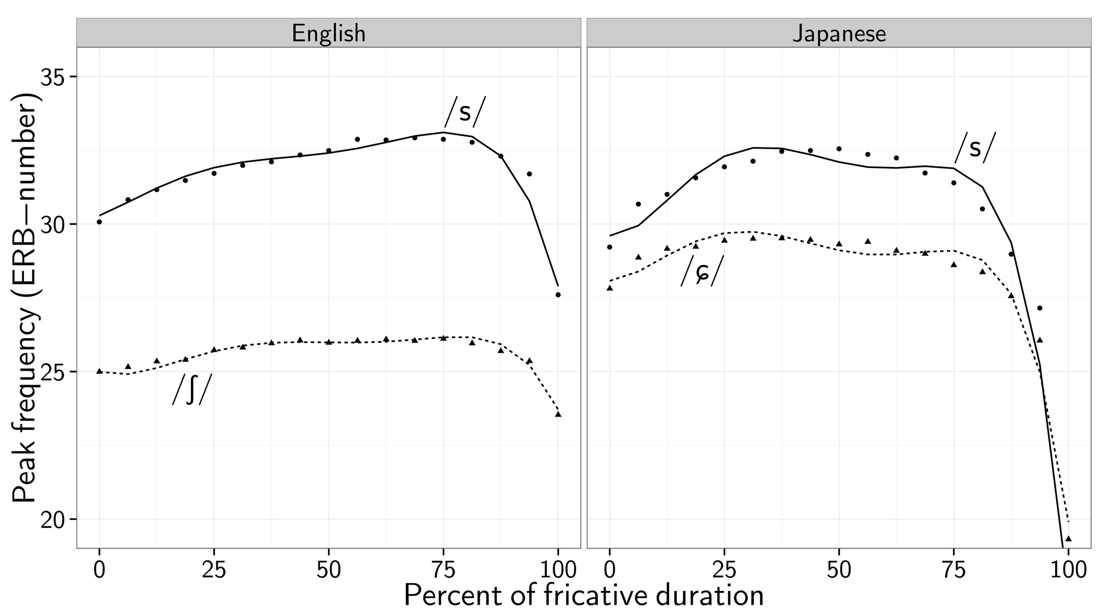
Figure 1: General placement of vowels along feature continua. Discretization of each continuum is marked by dotted lines.



Sibilant contrast

- ▷ English /s/ & /ʃ/: contrastive in all vowel contexts; /ʃ/ constriction more posterior, front cavity larger than /s/; /ʃ/ articulated with lip rounding.
- ▷ Japanese /s/ & /ɕ/: contrastive only in back vowel contexts; /ipaC/ constriction longer, more palatalized than /s/; both sibilants articulated with spread lips.
- ▷ In both languages, the sibilant contrast is indicated by static and dynamic aspects of spectral properties (cf. average trajectory level vs. trajectory shape in Fig. 2).
- ▷ Spectral resonances of English /s/ reported to be lower in round-vowel contexts, due to anticipatory lip rounding.

Figure 2: Temporal variation in peak ERB_N-number across the English and Japanese sibilants. Fixed-effects predictions of fifth-order polynomial growth curve models are shown as lines; data means, as points.



Methods

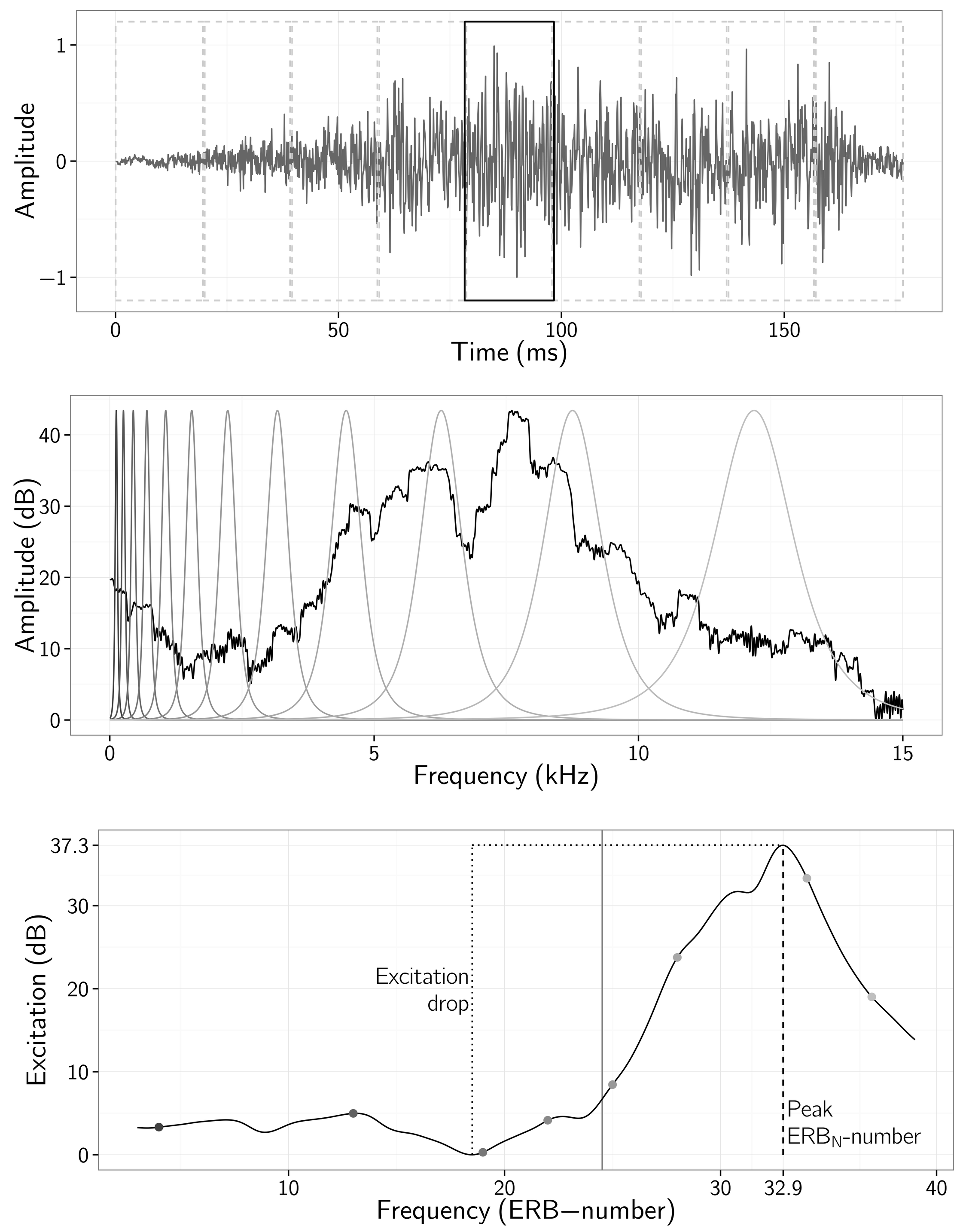
Participants & materials

- ▷ 20 adult native speakers (10 females, 10 males) for each language.
- ▷ Sibilants produced in prevocalic, initial position of real words.
  - – English vowels were grouped into five classes: {i}: /i, ɪ/; {u}: /u, ʊ/; {e}: /e, ɛ/; {o}: /o/; {ɑ}: /ʌ, ɑ, ɔ/.
  - – In each language, 3 target words per phonotactically legal combination of sibilant and vowel (class).
- ▷ Elicited with a picture-prompted repetition task.

Estimation of psychoacoustic spectral properties

- ▷ From each sibilant production, 17 excitation patterns were computed from 20-ms intervals spaced evenly across the frication (cf. Fig. 3).
- ▷ Psychoacoustic spectral properties computed from each excitation pattern:
  - ▶ *Peak ERB_N-number:* most prominent psychoacoustic frequency;
  - ▶ *Excitation drop:* difference in excitation (dB) between high-freq. peak and low-freq. trough (cutoff = 24.5 ERB_N-num. ≈ 3 kHz).
- ▷ Hence, each production represented with two 17-point trajectories.

Figure 3: Top: Waveform of /s/; odd-numbered 20-ms analysis windows overlaid. Middle: Multitaper spectrum estimated from middle window of /s/; gammatone filters overlaid. Bottom: Excitation pattern output by a 361-channel gammatone filter bank model of auditory periphery.



Analysis of vowel-context effects on spectral dynamics

- ▷ For each sibilant and spectral property, an orthogonal polynomial growth curve model was fitted to the trajectories: 8 models in total.
  - – Fixed effects: Vowel, $Time^n$ up to n = 5, and $Time^n$ × Vowel interactions. Built up with a stepwise forward-selection protocol.
  - – Random effects: Intercept and each power of $Time^n$ for talker and for vowel-within-talker.
- ▶ Interactions between Vowel and non-zero powers of $Time^n$ indicate differences in spectral dynamics conditioned by vowel context. These are of primary interest.

Results

Figure 4: Fixed-effects predictions of the growth curve models fitted to the peak ERB_N-number trajectories. The effects of Vowel included in a model's structure are shown in the bottom left corner of each panel. Each model also included a fixed effect of intercept and of each power of $Time^n$ up to n = 5.

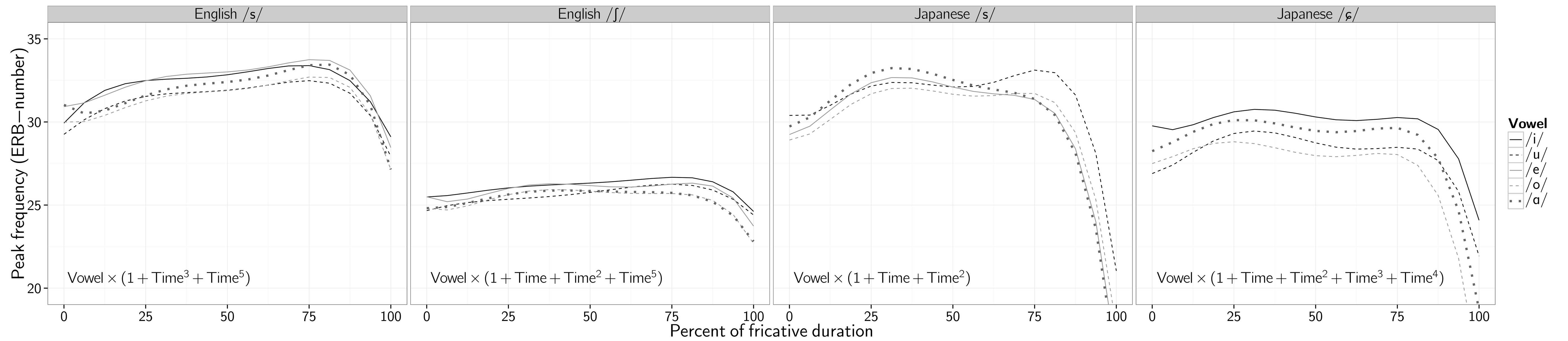
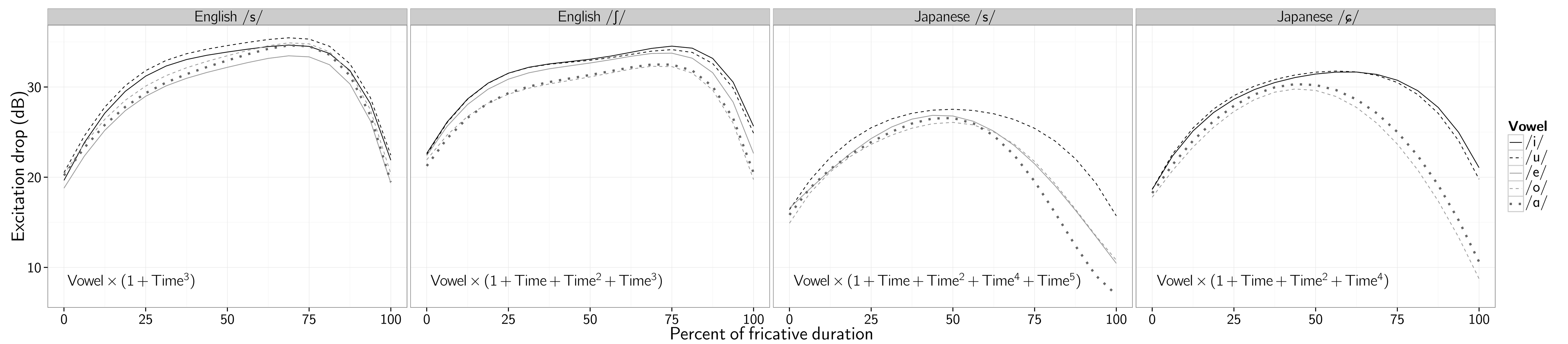


Table 1: Summary of Vowel coefficients in fitted models. Models were fitted with /ɑ/ as the reference level. Positive and negative effects are indicated by + and −, respectively. Significance was determined with Wald confidence intervals; shaded cells denote insignificant coefficients at the .05 level.

	Peak ERB_N-number													
	English								Japanese					
	/s/				/ʃ/				/s/			/ɕ/		
	/i/	/u/	/e/	/o/	/i/	/u/	/e/	/o/	/u/	/e/	/o/	/i/	/u/	/o/
Vowel	+	−	+	−	+	+	+	−	+	−	−	+	−	−
Vowel × Time					+	+	+	+	+	+	+	+	+	−
Vowel × $Time^2$					+	+	+	−	+	+	+	+	+	−
Vowel × $Time^3$	+	+	+	+								+	+	−
Vowel × $Time^4$												+	+	−
Vowel × $Time^5$	+	+	+	+	+	+	−	−						

	Excitation drop													
	English								Japanese					
	/s/				/ʃ/				/s/			/ɕ/		
	/i/	/u/	/e/	/o/	/i/	/u/	/e/	/o/	/u/	/e/	/o/	/i/	/u/	/o/
Vowel	+	+	−	+	+	+	+	−	+	+	+	+	+	−
Vowel × Time					+	+	+	−	+	+	+	+	+	−
Vowel × $Time^2$					+	+	+	+	+	+	+	+	+	−
Vowel × $Time^3$	+	+	+	+	+	+	+	−						
Vowel × $Time^4$									−	−	−	−	−	+
Vowel × $Time^5$									−	−	−			

Figure 5: Fixed-effects predictions of the growth curve models fitted to the excitation-drop trajectories. The effects of Vowel included in a model's structure are shown in the bottom left corner of each panel. Each model also included a fixed effect of intercept and of each power of $Time^n$ up to n = 5.



Discussion

- ▷ Significant main effects of Vowel indicated context effects on spectral statics (i.e., average level of spectral-property trajectory).
  - – Average peak ERB_N-number of English /s/ sensitive to vowel frontness and rounding; of English /ʃ/, only to vowel frontness.
  - – Average peak ERB_N-number of Japanese /ɕ/ sensitive to vowel frontness and rounding.
- ▷ Significant interactions between Vowel and non-zero powers of Time indicated context effects on spectral dynamics (i.e., shape of a spectral property's time course).
  - – Dynamics of peak ERB_N-number and exception-drop trajectories for both English /s/ and /ʃ/ were sensitive to vowel height.
  - – For Japanese /s/, dynamics of peak ERB_N-number and of excitation drop were sensitive to both vowel rounding (first half of frication) and vowel height (second half of frication). For Japanese /ʃ/, dynamics of peak ERB_N-number and of excitation drop were sensitive to height.
- ▶ The preponderance of context effects on non-zero powers of Time suggests the importance of jaw movement for the spectral dynamics of sibilant fricatives.

Acknowledgements

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