Weakening patterns of intervocalic voiced plosives in Japanese

3aSC23

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Background

- Japanese plosives : /p//b/,/t//d/, /k//g/

- Voiced plosives/b//d//g/ have been observed to exhibit weakened burst intensity, and in some instances, they may show a complete weakening with no observable burst.

- Maekawa (2018) investigated the weakening rate of voiced plosives in Japanese and its relationship with surrounding acoustic environments, using the Corpus of Spontaneous Japanese (CSJ).

- His study revealed a notable tendency for consonant weakening, particularly at positions characterized by weak prosodic boundaries.

Research Questions

- What pronunciation patterns exist for the weakening of plosive consonants in Japanese?

- What articulatory movements are producing these weakening patterns?

Methods

Participants & Stimuli

- **Participants**: 9 native Japanese speakers

Table 1: Participants

Speaker	Gender	Age	Region
CJF01	F	18	Kanagawa
CJF03	F	20	Fukushima/Tokyo
CJF04	F	19	Aichi/Melbourne/Chiba
CJF05	F	21	Shizuoka/Tokyo
CJF06	F	22	Tokyo
CJF07	F	21	Kanagawa
CJM01	M	25	Tokyo
CJM02	M	20	Tokyo
CJM03	M	20	Singapore/Tokyo

- **Stimuli**: Non-lexical "aCa" sequences
  Consonants = "p/b, t/d, k/g"

- Pronounced in a carrier phrase (/korewa ___ to i:masu/ 'this is called ___').

- Repeated × 10 with 2 pitch accent patterns(High-Low & Low-High), randomized

- Here, we will only discuss voiced plosives.

Audio & Ultrasound Recording

- The audio signal was digitally recorded at 22,050 Hz, 16-bit resolution, using a RODE-NT2-A microphone.

- Mid-sagittal images of the oral cavity were recorded with an ultrasound system (MicrUS, EXT-1H) using a microconvex probe (MC10-5R10S-3). Video frame rate was 113fps.

- The audio signal and ultrasound video were recorded simultaneously and synchronized using AAA software.
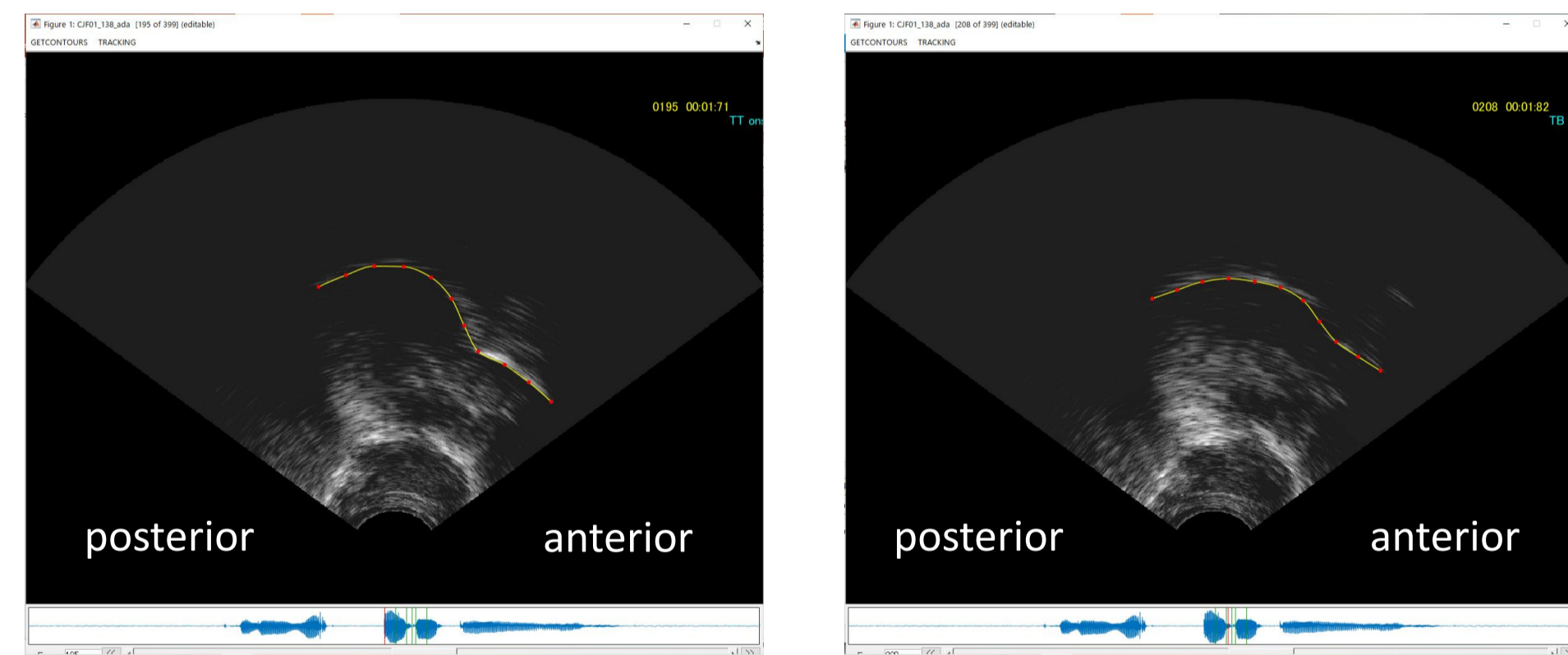
Analysis

- **Acoustic analysis**: 540 tokens (3 consonant × 10 repetitions × 2 pitch accents × 9 speakers) were segmented using Praat and classified according to the weakening patterns.

- **Ultrasound image analysis:**

I. /ada/ & /aga/ were analyzed (250 tokens total).

II. The tongue contour of two frames were tracked based on the articulatory gesture using GetContours.

1st: the onset of consonant articulatory movements of /ada/
2nd: the maximal constriction point of /ada/

III. Figures were plotted overlaying utterances from each speaker based on weakening patterns → to visualize the progression of tongue movements.

IV. The predicted tongue contours at the maximal constriction point from the repetitions were plotted by speaker for each weakening pattern using a generalized additive model (GAM). → to clarify the correlation between consonant weakening in plosives and constriction created by the tongue.

V. Instances with synchronization errors or images too unclear for tracking were excluded from the analysis.

References:
[1] K, Maekawa. 2018. Weakening of Stop Articulation in Japanese Voiced Plosives. Journal of the Phonetic Society of Japan. 2018 Jun, 22(1), 21-34.
[2] P. Boersma, D. Weenink, "Praat: Doing phonetics by computer. Version 6.1.42, retrieved 2021 from http://www.praat.org/," 2021.
[3] Tiede, M. K. 2022. GetContours. GitHub repository, https://github.com/mktiede/GetContours.
[4] S. N. Wood. Generalized additive models: an introduction with R. chapman and hall/CRC, 2006.
[5] Warner N, Tucker BV. 2011. Phonetic variability of stops and flaps in spontaneous and careful speech. J Acoust Soc Am. 130(3), 1606-17.

Results

Weakening Patterns

- ⓪ With burst pattern

- ① Voiced glide pattern ➡ involves the complete absence of burst with sustained vocal fold vibration

①-1

- ② Voiced frication pattern ➡ includes frication weakening of burst with sustained vocal fold vibration

- ③ Pattern with halted vocal fold vibration and weak aspiration ➡ arises from frication weakening of burst with incomplete vocal fold vibration

- **Perception:** A significant portion of utterances with consonant weakening is still perceived as voiced plosives (e.g.①-1), while other instances resemble glides or fricatives.

- Utterances exhibiting glide-like perception retain vowel-like waveforms in the acoustic closure interval (e.g.①-2), suggesting potential incompleteness in articulatory closure formation. However, only marginal differences were observed in tongue position (**Figure 1**).
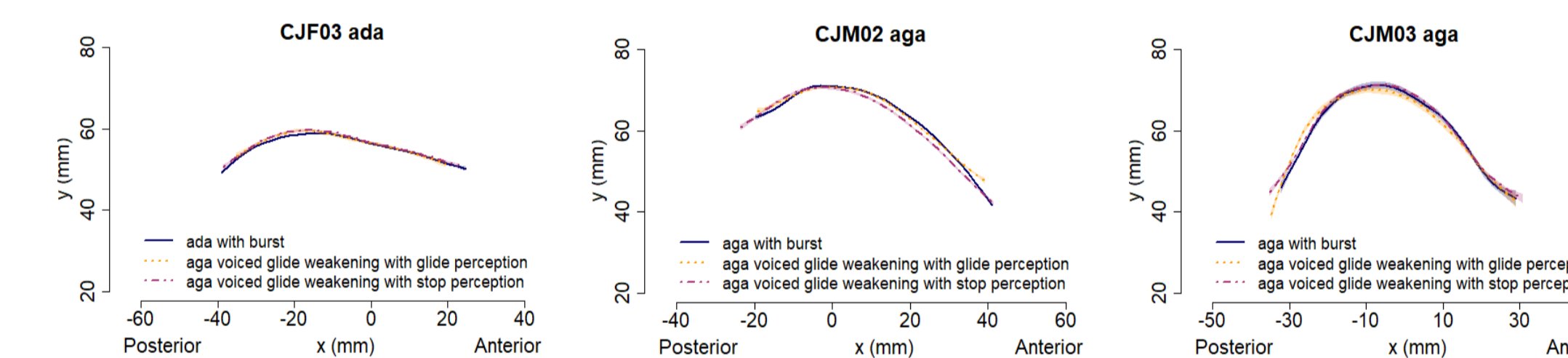
①-2

Figure 1: Tongue contours for CJF03/ada/, CJM02/aga/ and CJM03/aga/ through GAM plots with 95% confidence intervals.

Individual Variation

- Some speakers exhibit consistently low rates of weakening across all consonants, while others, excluding the low weakening rate of /d/, pronounce /b/ and /g/ with almost no burst.

- Most speakers demonstrated distinct tongue movements with and without weakening (CJF06/aga/, **Figure 4** top 3 pictures).

- CJF03/aga/(bottom) exhibited not only a higher rate of weakening but also appeared to have minimal tongue movement. It is more suggestive of unclear articulation rather than consonant weakening.
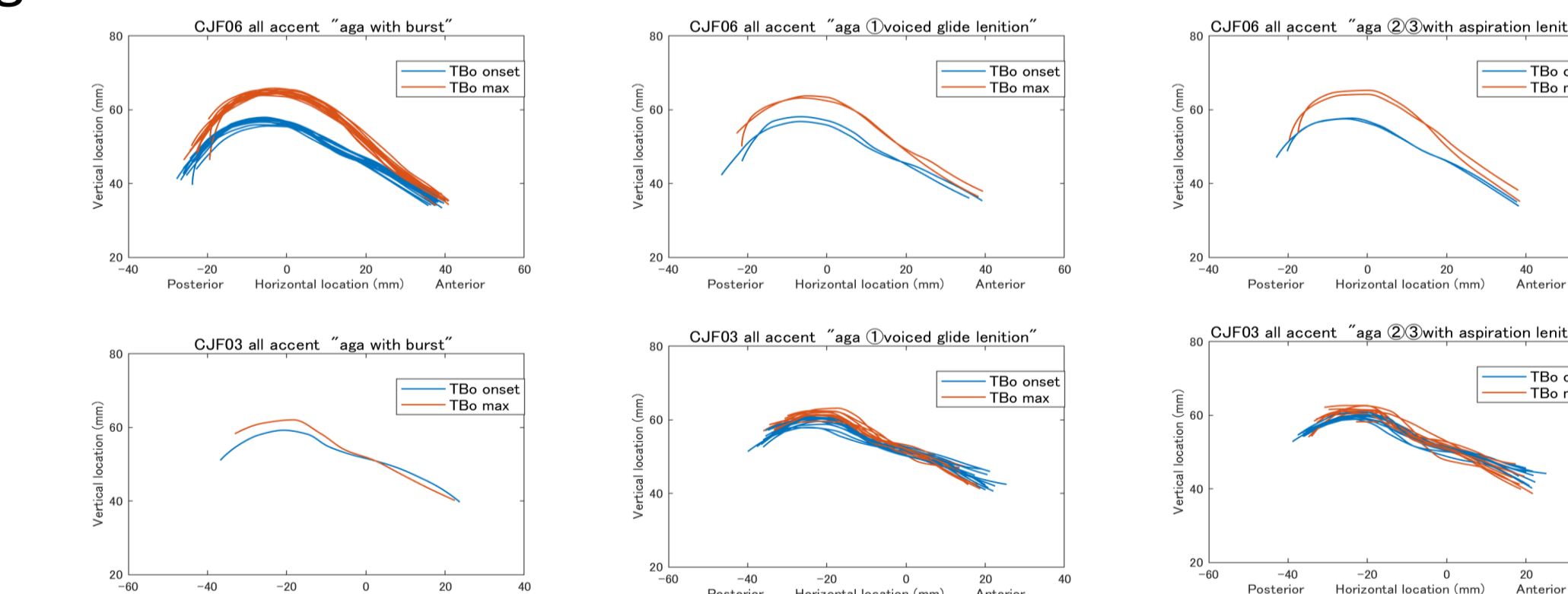

Figure 4 : Tongue contours of tongue body gesture onset and max for CJF06/aga/ & CJF03/aga/.

Is Frication Higher than Glide?

- Ultrasound images for different weakening patterns were plotted by GAM model and visually compared.

- The height of the tongue contours at the maximal constriction point: ⓪>②③>① (e.g. CJF05/ada/).
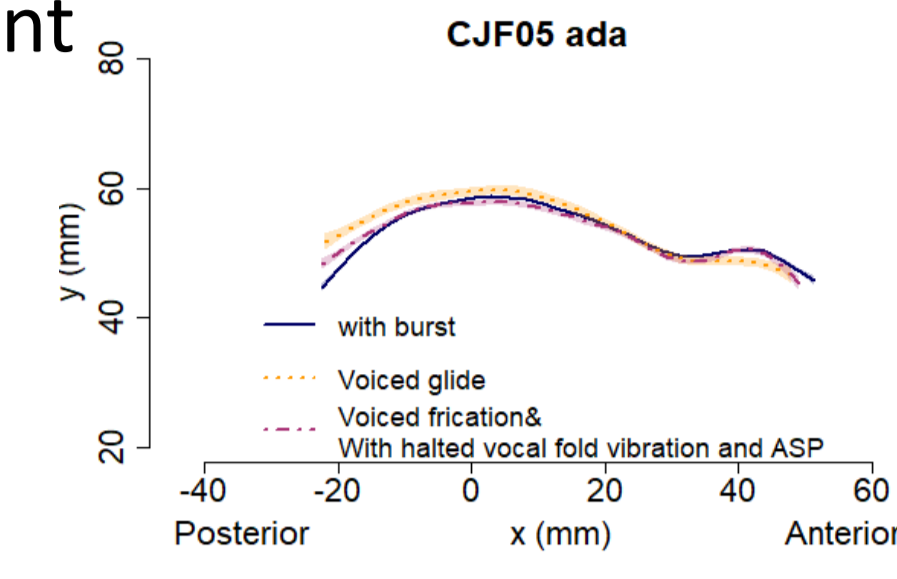

Figure 2: Tongue contours for CJF05/ada through GAM plots with 95% confidence intervals.

Table 2: List of tongue highest point height rankings by speaker and weakening pattern (excluding data whose ultrasound images cannot be analyzed)

Weakening pattern	CJF01 /ada/	CJF03 /ada/	/aga/	CJF05 /ada/	/aga/	CJF06 /ada/	/aga/	CJF07 /ada/	CJM02 /ada/	/aga/	CJM03 /ada/	/aga/	Average rank
⓪With burst	1	2	1	1	—	—	2	3	2	1	1	1	1.15
①Voiced glide	2	1	3	3	1	2	3	2	3	3	2	2	2.09
②③ Frication	1	1	1	2	1	1	1	1	1	2	3	2	1.54

Influence of Place of Articulation

- Differences in the frequency of weakening patterns observed in different places of articulation (**Table 3**).

- ⓪with burst: /d/ > /b/ > /g/, different from the tendency observed in English(Warner&Tucker,2011), but confirmed the results in Maekawa (2018).

- Maekawa attributed this sequence in Japanese to the complexity of the phonemic contrast among the place of articulation within the phonological system.

  Alveolar → plosive /d/, affricate /z/, nasal /n/
  Bilabial → plosive /b/, nasal /m/
  Velar → plosive /g/

Table 3: Number of weakening pattern utterances for each place of articulation and accent

Place of Articulation	Accent	⓪With burst	①Voiced glide	②Voiced frication	③With halted vocal fold vibration and ASP
/b/	HL	35	43	5	7
	LH	47	29	12	2
	ALL	82	72	17	9
/d/	HL	62	12	13	3
	LH	75	7	7	1
	ALL	137	19	20	4
/g/	HL	25	30	27	8
	LH	43	22	23	2
	ALL	68	52	50	10

Influence of Pitch Accent

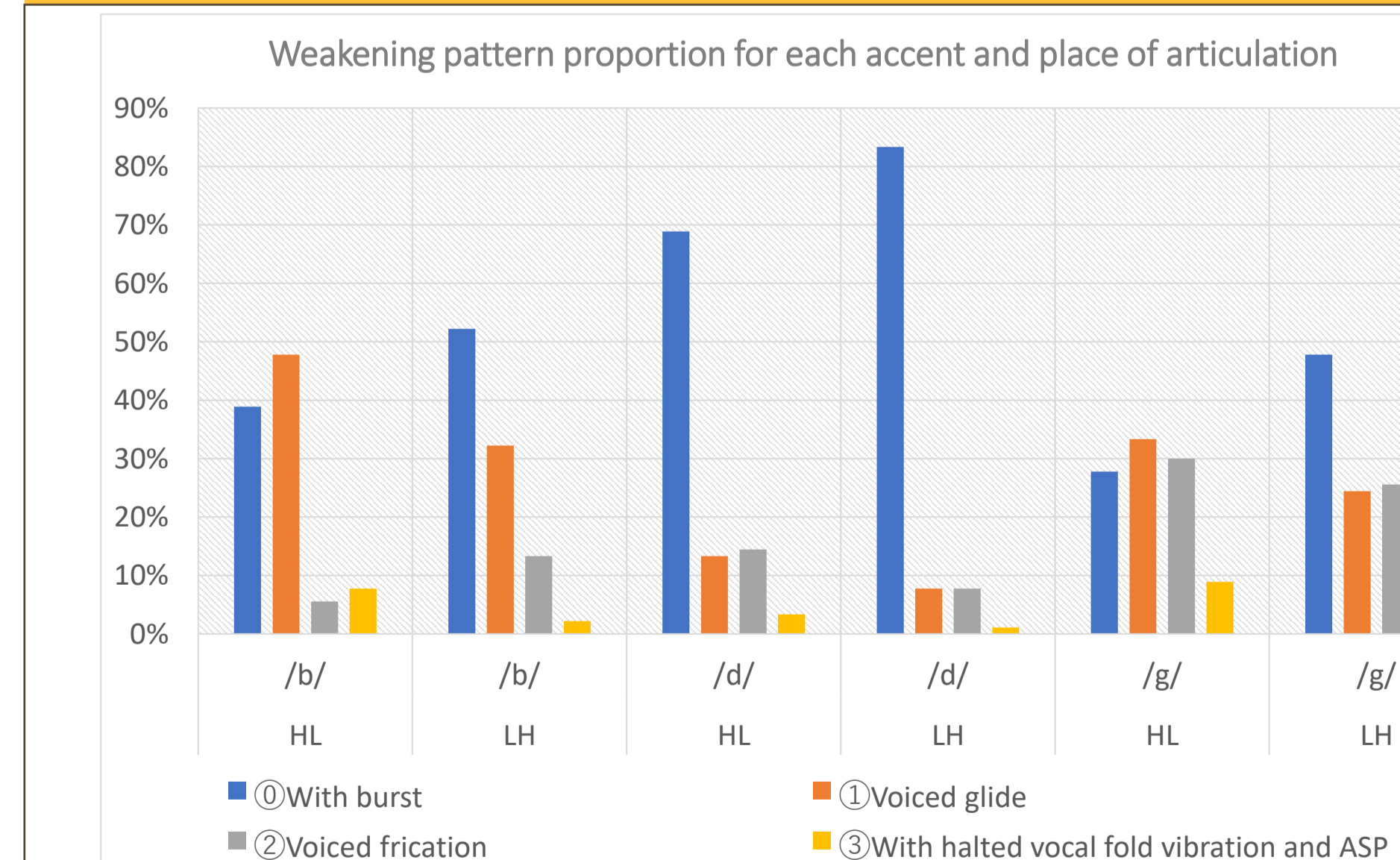Weakening pattern proportion for each accent and place of articulation

Figure 3 :Weakening pattern proportion for each accent and place of articulation

- LH patterns exhibited lower rates of weakening compared to HL patterns, with a tendency for increased susceptibility to weakening when there was a pitch fall.

Conclusion

- In Japanese, intervocalic voiced plosives undergo weakening not only in spontaneous, natural speech but also in careful speech recorded in a controlled lab environment.

- This weakening can be categorized into three patterns based on the degree of obstruction and the persistence of vocal fold vibration: ① Voiced glide pattern, ② Voiced frication pattern, and ③ Pattern with halted vocal fold vibration and weak aspiration.

- The susceptibility to weakening is influenced not only by the strength of intonational boundaries but also by accent patterns.

- There were differences in the frequency of weakening patterns depending on the place of articulation.

- There is individual variation in the rate of weakening.