Geminates are not just longer singletons: evidence from Italian articulatory data

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In this paper, we argue, based on articulatory data on Italian singleton and geminate consonants, that geminates are not simply a longer version of singletons, as often assumed in phonological analyses. Geminates differ from singletons along a variety of dynamically specified parameters that are included in the Task-Dynamic model of articulatory phonology [1], such as constriction target, stiffness, and movement amplitude/velocity. Since the differences in dynamically specified parameters persist once duration is taken into account, we propose that they should be part of the phonological representation of geminates.

Methodology: Preliminary data was analyzed from a native speaker of Italian who completed two separate experimental sessions. The participant produced six nonce disyllabic words VCV containing all singleton and geminate Italian bilabial consonants: [ipa, ippa, iba, ibba, ima, imma]. Target words were embedded in a carrier sentence [dika __ due vɔlte] "please say __ two times". Participants were cued to produce trials at five different rates "very slow", "slow", "normal", "fast", "very fast". Each word was repeated 10 times at each rate. In total participants produced 6 (target words) × 5 (rates) × 10 (repetitions) × 2 (sessions) = 600 tokens.

Articulatory data were collected at a sampling frequency of 400 Hz using an NDI Wave electromagnetic articulometer (EMA). In this paper, we focus on the articulation of bilabial consonants. Bilabial consonant closures and releases were identified algorithmically using a lip aperture (LA) time series and its velocity zero crossings. LA is defined as the Euclidean distance between the vertical and horizontal components of the Lower Lip and Upper Lip movements.

The following nine dependent variables were extracted for statistical analysis:

- Duration of the consonantal closure and release gestures (1-2).
- Maximum constriction degree of LA (3)
- Amplitude of closure and release (4-5)

$$A_{Closure/Release} = \left|LA\ Value_{Onset/Offset} - LA\ Value_{Minimum}\right|$$

- Peak velocity of closure and release ($v*_{Closure/Release}$) (6-7)
- Stiffness of closure and release (8-9) [2]

$$k_{Closure/Release} = \frac{v*_{Closure/Release}}{A_{Closure/Release}}$$

All dependent variables were entered in linear mixed-effect regression models. The fixed effects are utterance duration (z-scored) and geminate (with reference as "singleton"). Models were selected in a stepwise pruning procedure by first eliminating the effect of geminates. Random effects are random intercepts for subject session and for voicing/manner, i.e., whether the consonant is [p], [b], or [m]. Entire LA trajectories, time-warped to a fixed length from onset to offset, were also analyzed using generalized additive mixed models (GAMMs) [3].

Results: The results of the mixed effect linear regression analyses show that geminates have a significantly longer duration and higher constriction degree than their singleton counterparts. We also observed that geminates have larger movement amplitude, higher peak velocity, and lower stiffness than singletons for both the closure and the release phases. The summary of the result is as follows:

	Closure	**Release**
Constriction degree	G > S	*NA*
Amplitude	G > S	G > S
Peak Velocity	G > S	G > S
Stiffness	S > G	S > G

The results of the GAMM analyses shows that the whole LA trajectory of geminates is different from the trajectory of singletons, as shown in Figure 1.

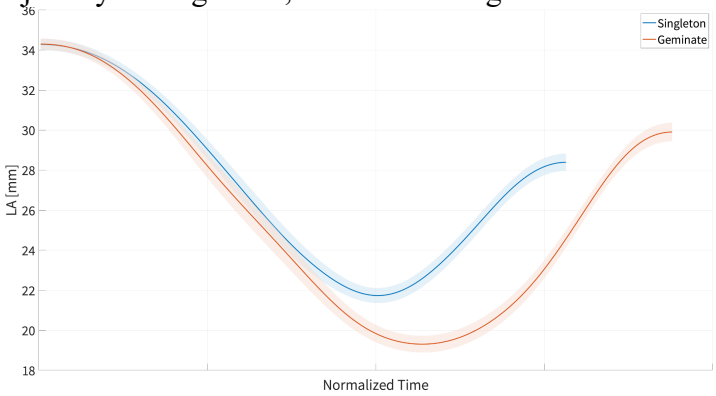

Figure 1. *LA trajectories of singletons and geminates and their 95% confidence intervals*

Discussion: Our results show that geminates are different from singletons, not only in their articulatory durations, but also in their constriction degree, stiffness, and peak velocity. There are two possible interpretations of the results. One interpretation is that underlyingly geminates and singletons are different solely in duration and other differences observed are the by-product of differences in duration. For example, singletons are less constricted, because of an undershoot due to shorter duration. The undershoot can also result in other observed behaviors: lower amplitude, lower peak velocity, and higher stiffness. This interpretation would be in line with phonological representations that analyze geminates as a longer version of their singleton counterparts, such as the representations in Figure 2.

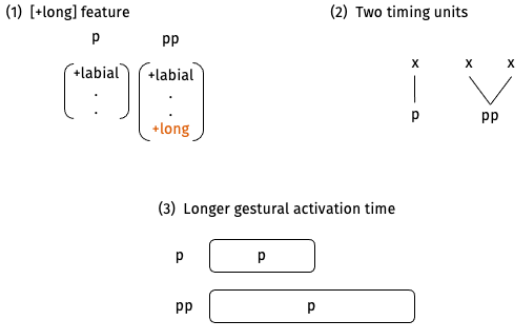

Figure 2. *Three phonological representations of singletons and geminates*

An important prediction of this account is that singletons that are as long as geminates should have nearly identical kinematic profiles to singletons. Our analyses, however, show that geminates remain distinct from singletons, even once durational effects are taken into account in the statistical models. The conclusion we draw is that the lexical difference is not simply a matter of duration, but also of phonologically specified differences in values of kinematic parameters. In turn, a revised interpretation of the contrast between singleton and geminates suggests that phonological contrasts have a richer phonetic substance than often assumed, in line with the claims of a unified approach to phonology and phonetics, like Articulatory Phonology [4].

References: **[1]** E. Saltzman and K. Munhall, "A dynamical approach to gestural patterning in speech production," *Ecological psychology*, vol. 1, no. 4, pp. 333–382, 1989. **[2]** C. Zeroual, S. Fuchs, P. Hoole, and J. H. Esling, "Kinematic study of Moroccan Arabic simple and geminate obstruents: Evidence from transillumination," *Proc. 7th ISSP*, pp. 287–294, 2005. **[3]** S. N. Wood, *Generalized Additive Models: An introduction with R*. Chapman & Hall, 2017. **[4]**C. P. Browman and L. Goldstein, "Articulatory phonology: An overview," *Phonetica*, vol. 49, no. 3–4, pp. 155–180, 1992.