Nonlinear effects of speech rate on articulatory timing in singletons and geminates

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Not much is known about how singleton and geminate consonants vary with speech rate. One possibility is that singleton and geminate timing intervals are related to one another by a fixed factor and scale linearly with speech rate. To test this, we investigated how intra- and intergestural timing varies with word duration in intervocalic /m/ and /mm/ from speakers of Tashlhiyt Berber, Japanese, and Italian. We found that timing intervals in singletons exhibited a stronger nonlinear relation with word duration than timing intervals in geminates. Moreover, singleton and geminate timing interval variances and standard deviations were not linearly related to interval means. A secondary finding was a substantial difference with regard to the timing of consonantal and vocalic gestural onsets. Together these patterns indicate that articulatory timing in singleton and geminate consonants cannot be understood simply as linear scaling under speech rate.

Motivation: A key aspect of our approach is experimental elicitation of a wide range of speech rates. Rate variation is important because it allows us to test a simple model of timing control in which (i) the duration of an interval is a linear function of a global rate variable and an intrinsic segmental duration parameter, and (ii) variance or standard deviation is proportional to mean interval duration (both are common relations in psychophysical studies). The study was designed to maximize our ability to infer statistical relations between rate and interval mean/variance by focusing on /m/ and /mm/ in one phonological environment (/i__a/), in language-specific carrier phrases. Analyses described below treat the duration of /ima/ as a proxy for speech rate.

Method: We recorded 3 speakers (S1: Tashlhiyt Berber, S2: Japanese and S3: Italian) with an electromagnetic articulograph (AG 501). The target words were /ima/ and /imma/ for all languages. These were embedded in carrier phrases shown in the table. To elicit variation in speech rate, we used a visual analogue for rate. The visual cue was a red box that moved across the screen over a range of rates. Each speaker produced a total of 320 repetitions of /ima/ and /imma/. Articulatory data were labelled as in Fig. 1 (right), using a velocity-based algorithm for identification of onsets and targets.

Language	**Carrier**	***Gloss***
Tashlhiyt	Innajam __ bahra.	*He told you __ a lot.*
Japanese	Kore wa __ nano.	*This is __.*
Italian	Parli con __ per favore.	*Talk to __ please.*

Results: Our main finding is that articulatory timing intervals in singletons, to a greater extent than in geminates, scale nonlinearly with target word duration. This can be seen in Figure 1 (top row), which shows exponential and linear model fits of the bilabial closure onset-to-release interval (y-axis) as a function of word duration (x-axis). Comparisons of exponential and linear fits using the Akaike Information Criterion support this interpretation. Secondly, we did not find evidence for linear mean-variance or mean-standard deviation relations (Figure 2). Third, analysis of intergestural timing between consonantal and vocalic gestures (Figure 1 bottom row) differed substantially across speakers: for S1, this interval scaled exponentially with rate for singletons, and was nearly flat for geminates; in contrast, S2 and S3 have relatively constant interval durations for both singletons and geminates.

Conclusion: Our findings are important because they show that articulatory timing in intervocalic singletons and geminates cannot be controlled by a single mechanism with a linear speech rate factor. Instead, the nonlinearities and between-speaker (or cross-language) differences indicate that control mechanisms themselves may vary with rate. We discuss possible interpretations of the patterns in the context of Articulatory Phonology (Browman & Goldstein 1989, 2000) and Selection-coordination theory (Tilsen 2016).

Figure 1: Exponential and linear model fits of articulatory timing intervals. Top row: bilabial closure onset to release interval as a function of word duration. Bottom row: Bilabial closure to onset to vowel onset as a function of word duration. Right: example of articulatory events in timeseries of lip aperture (LA) and tongue body 1st principal component.

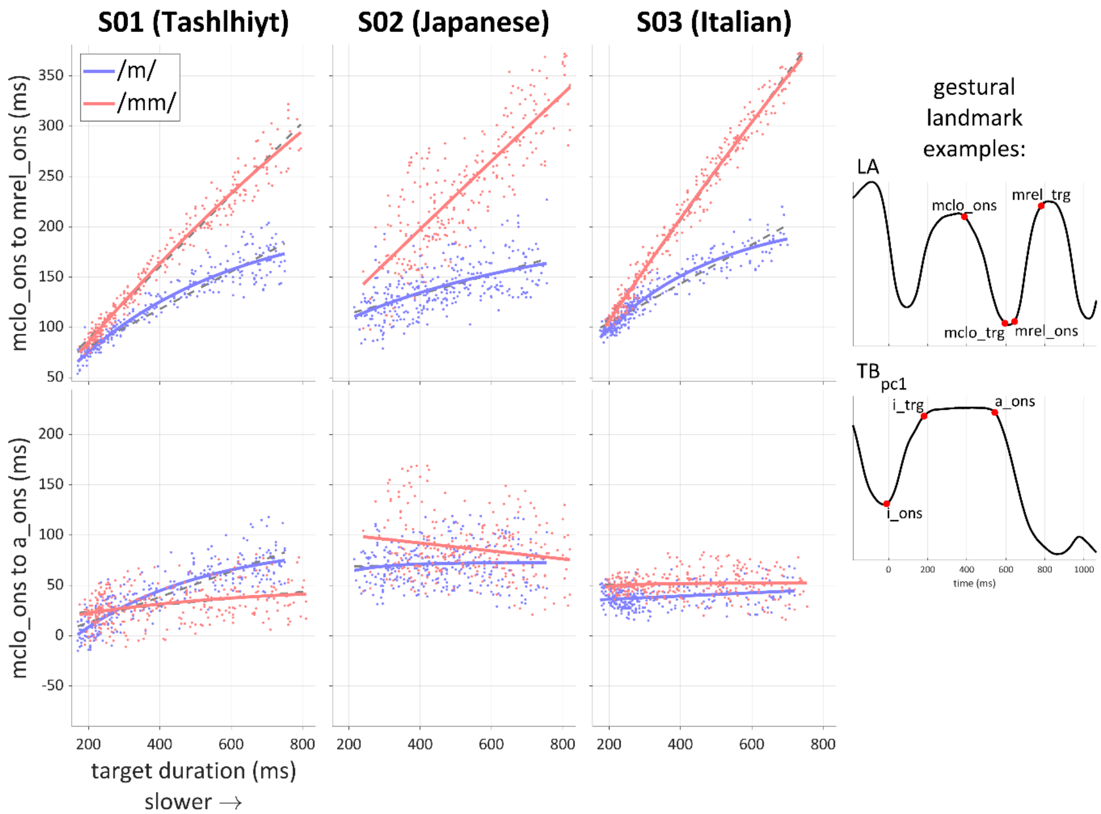
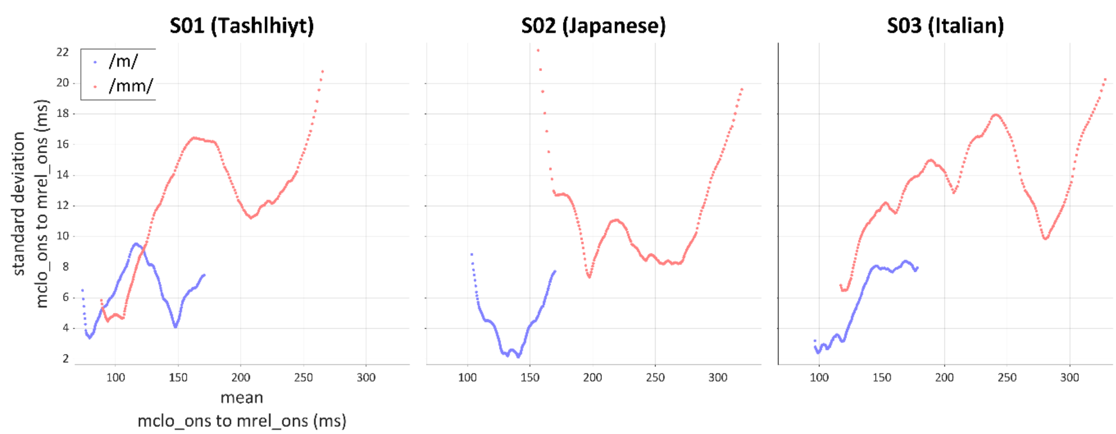


Figure 2: Relation between mean and standard deviation. Standard deviations and means are estimated with a moving window of 50 observations.



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