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## Cross-linguistic timing contrast in geminates: A rate-independent perspective

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### Abstract

*In this study, we aim to gain insights into whether there exists an invariant durational property which can uniquely distinguish between singletons and geminates, both across languages and across speech rates. We collected acoustic data from four typologically distinct languages (Tashlhiyt, Japanese, Italian and Finnish) and so far, recorded one speaker from each language producing 320 times /ima/ and 320 times /imma/ within a carrier phrase, across a wide range of speech rates (20 different steps). Several temporal parameters as well as relational measures that are generally associated with gemination distinction were analyzed. Results show that in none of the four languages absolute consonant duration can reliably distinguish singletons and geminates across different speech rates. However, the ratio of consonant to word duration across speech rates provides a rate-invariant boundary that can accurately distinguish the two phonemes in the four languages. These results provide support for previous work, and suggest that a cross-linguistic rate-independent attribute of gemination is not absolute but relational.*

**Keywords:** Geminates, duration, acoustic invariance, speech rate, cross-linguistic approach

### 1. Introduction

Various languages across the world use length to lexically contrast between two sets of consonants: singletons and geminates (Kubozono 2017). For example, in Tashlhiyt /m/ and /mm/ are in opposition with each other, allowing to contrast the pair [imi] ‘mouth’ and [immi] ‘(grand)mother’. The consonants /m/ and /mm/ are minimally contrastive in that they differ in just one property, gemination (or length). Most phonologists and phoneticians agree that gemination is realized in terms of absolute durational differences, with geminates being longer than their singleton counterparts (Ladefoged and Maddieson 1996, Lehiste 1970, Lahiri & Hankamer 1988, Payne 2005, Kawahara 2015, see Ridouane 2010 and references therein). Still, one major challenge comes from the extreme variability in the way duration is implemented. This variability is a consequence of several interacting constraints, both structural (e.g., language-specific phonological systems) and physical (e.g., speech rate).

This preliminary study is part of a project exploring how these structural and physical constraints interact in shaping the way length contrast is acoustically implemented in typologically unrelated languages. It aims at determining whether an invariant property can realize the same length contrast across languages and speech rates. We present results for Tashlhiyt, Japanese, Italian and Finnish. Gemination is lexically contrastive in these four languages, but with markedly variable phonetic realizations, and within different phonological systems (e.g., Japanese is mora-timed while Italian is syllable-timed; Japanese and Finnish have length contrast for both

consonants and vowels, while only consonants contrast in length in Tashlhiyt and Italian).

#### 1.1 Secondary attributes of gemination

Previous studies have also shown that additional phonetic features may be involved in signaling gemination contrast (Engstrand & Krull 1994, Payne 2006, Ridouane 2010, Kawahara 2015), but these additional attributes vary depending on languages. One example is the effect of gemination on the preceding vowel. In some languages, vowels tend to shorten before geminates, as in Bengali (Lahiri & Hankamer 1988), Tashlhiyt (Ridouane 2010), Hindi (Ohala 2007), Malayalam (Local & Simpson 1988), and Italian (Esposito & Di Benedetto 1999). But in other languages, vowels are lengthened before geminates, as in Japanese (Kawahara 2015), Turkish (Jannedy 1995), Finnish (Lehtonen 1970), and Shinhara (Letterman 1994). Other languages show no effect of gemination on preceding vowel duration, as in Lebanese Arabic (Khattab & Al-Tamimi 2014), Palestinian Arabic (Miller 1987), Tamil (Keane 2001), and Estonian (Engstrand & Krull 1994).

The effect of gemination on the following vowel has not been studied as much. In Japanese, vowels are reported to be slightly shorter after geminates (Han 1994, Idemaru & Guion-Anderson 2008, Ofuka et al. 2005). This shortening, however, is not very substantial ( $\Delta=9$  ms in Han 1994;  $\Delta=13$  ms in Idemaru & Guion 2008), and is much less consistent (Kawahara 2015). A similar insubstantial shortening has also been reported for Italian (Yoshida et al. 2015), while no effect has been observed in Tashlhiyt (Ridouane 2007).

#### 1.2 Gemination and speech rate

As shown in previous studies by inter alia Pickett et al. (1999), Pind (1995) and Hirata & Whiton (2005), speech rate may affect singletons and geminates differently. A specific question has been addressed in these studies, i.e., asking whether there is any acoustic correlate that is invariant across different speech rates. The findings suggest that this invariant measure is a relational one.

Pickett et al. (1999) analyzed Italian words contrasting singletons and geminates, spoken in isolation and in a sentential context at two different rates: slow and fast. Closure duration was found to discriminate between the two categories of consonants within a given speaking rate, but this measure failed to discriminate the two categories across the two speech rates. However, a measure reflecting the relation, i.e., the ratio between consonant duration and preceding vowel duration (C/V), allowed to discriminate between singletons and geminates both within and across speaking rates.

Hirata & Whiton (2005) analyzed Japanese tokens of singletons and geminates in real words and nonce words at three different speech rates: slow, normal, and fast. Three

measures were evaluated on their effectiveness in correctly classifying singleton and geminate tokens: closure duration, C/V ratio, and C/W ratio. Their results showed a significant amount of overlap between singletons and geminates across the three rates, implying, as for the Italian study, that closure duration could not classify the two categories. Similar to Italian, relational measures classified accurately singletons and geminates, with the highest accuracy for C/W (98% for nonce words and 95.7% for real words).

In the present study, we build on these findings, and make a novel empirical contribution to the debate over the existence of an acoustic invariant of gemination. The novelty of this study lies in the inclusion of four typologically distinct languages, and in the use of a motion-based cue to elicit much more variation in speech rates than in previous studies.

## 2. Methods

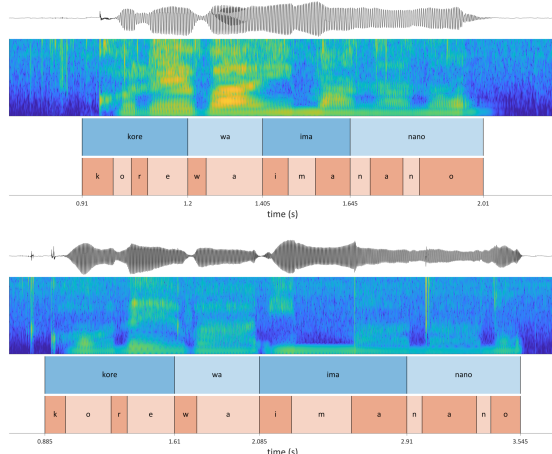
We recorded four speakers, one speaker of Tashlhiyt (S1), one of Japanese (S2), one of Italian (S3), and one of Finnish (S4). The acoustic data were recorded using a condenser microphone (AKG C420 headset) sampled at 48kHz, 16bit.

The target words /ima/ and /imma/ were embedded in language-specific carrier phrases (shown in Table 1). Each speaker produced a total of 320 repetitions of /ima/ and 320 repetitions of /imma/.

**Table 1:** Languages-specific carrier phrases.

Language	Carrier Phrase	Gloss
Tashlhiyt	Innam _ bahra.	<i>He told you _ a lot.</i>
Japanese	Kore wa _ nano.	<i>This is _.</i>
Italian	Parli con _ per favore.	<i>Talk to _ please.</i>
Finnish	Ottakaa _ mukaan.	<i>Talk to _ please.</i>

We applied forced alignment to the acoustic data with monophone HMMs using Kaldi. Separate HMMs were trained using 32 manually aligned responses from each speaker. The alignments were visually inspected for accuracy and corrected when necessary. No distinction between singleton and geminate phones was imposed in the models.

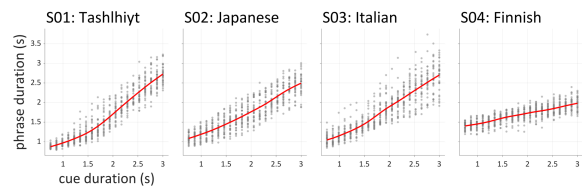


**Figure 1:** Forced alignment annotation example for Japanese speaker for singleton /ima/ (top) and geminate /imma/ (bottom) embedded in carrier phrase <Kore wa \_ nano>.

## 2.1 Rate manipulation

To elicit variation in speech rate, we used a motion-based cue for rate. The cue was a red box that moved across the screen over a range of rates (ranging in 20 steps from minimum cue duration of 0.750s to maximum cue duration of 3s). The speakers were instructed to produce the phrases at the same pace as the moving box, after it moved off the screen. We did two sets of the recordings, one from where speech rate was ranging from slow to fast and one from fast to slow.

To mitigate the potential for confounding effects of differences in rate control strategies, we explicitly instructed speakers not to pause between words and instead to control their rate by producing the words of the phrase more slowly. As Fig. 2 shows, the task for this study was rather successful. Phrase durations span a wide range (95% density intervals spanned 2.07 s, 1.74 s, and 2.09 s for S01, S02, and S03, respectively). A slight departure from these patterns was observed for the Finnish speaker (S04), who shows a smaller range of variation in speech rate.



**Figure 2:** Carrier phrase duration against cue duration for each language. Red lines show spline fits.

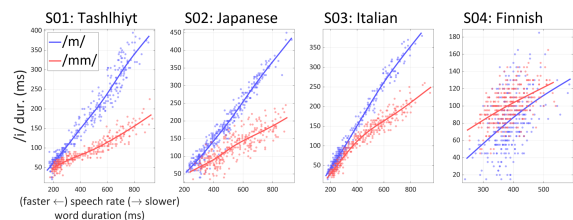
Because rate variation may be manifested differently in different words of the carrier phrase, and may differ across languages, the target word duration, rather than phrase duration, is taken as the index of rate.

## 3. Results

The results for absolute durations of the preceding vowel /i/, the following vowel /a/, and the consonants /m/ and /mm/ will first be presented, and followed by the relational measure of the duration of singletons/geminates relative to word duration.

### 3.1 Preceding vowel duration

Fig. 3 displays smoothing spline fits of the duration of /i/ as a function of speech rate (i.e., word duration). It shows that in three of the four languages (Tashlhiyt/S01, Italian/S02 and Japanese/S03) preceding vowels are shorter before geminates (represented in red) than singletons (represented in blue).



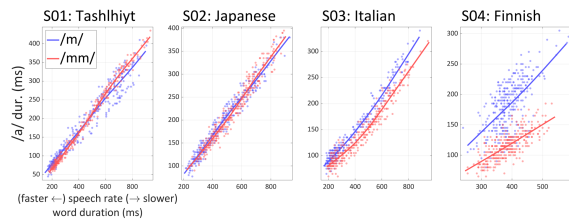
**Figure 3:** Segmental duration of /i/ as a function of word duration/speech rate. (Blue=singleton, red=geminate).

Furthermore, speech rate effects on this preceding vowel were smaller before geminates than before singletons. A consequence of this is that the durational differences in preceding vowels are more important as rate decreases. Such differences were not observed for Finnish, although this could

be attributable to the smaller range of rates elicited from this speaker.

### 3.1 Following vowel duration

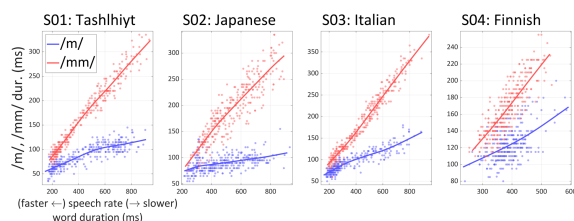
Fig. 4 displays spline fits of the duration of following /a/ across speech rate. Unlike for the preceding vowel, the interaction with the following vowel was similar across singletons and geminates. The following vowel was thus not affected whether preceded by a singleton or a geminate in Tashlhiyt, Japanese and Italian (Finnish perhaps being an exception). Thus, gemination interacts with the preceding vowel more strongly than it does with the following vowel.



**Figure 4:** Segmental duration of /a/ as a function of word duration/speech rate. (Blue=singleton, red=geminate).

### 3.3 Singleton/geminate duration

Fig. 5 shows the results for the duration of singleton /m/ and geminate /mm/ across speech rate. Geminate durations scaled approximately linearly with rate in the four languages (in red), suggesting they were more affected by speech rate than singletons (in blue).



**Figure 5:** Segmental duration of /m/ and /mm/ as a function of word duration/speech rate. (Blue=singleton, red=geminate).

When speech rate was slowed down, the differences in absolute durations between singletons and geminates were further enhanced with a remarkable increase in geminate durations. Thus, the biggest durational differences between singletons and geminates were observed at slower rates. This is also shown in Table 2, where the fastest and the slowest speech rates are compared. The values indicate that the durational difference between geminates and singletons was smaller at the fastest rate ( $\Delta=20$  ms (S01),  $\Delta=55$  ms (S02),  $\Delta=28$  ms (S03),  $\Delta=25$  ms (S04)) than at the slowest rate ( $\Delta=166$  ms (S01),  $\Delta=148$  ms (S02),  $\Delta=169$  ms (S03),  $\Delta=74$  ms (S04)).

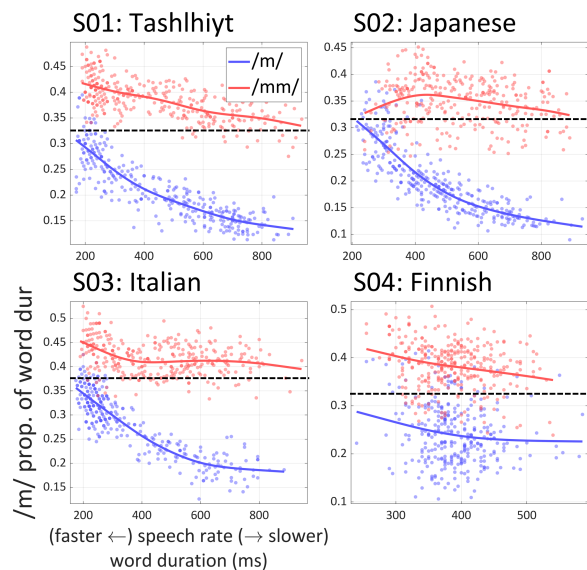
The results also show that singletons at slower rates may overlap with geminates at faster rates. This is true for the four languages under investigation (see the numbers in grey boxes in Table 2). In Tashlhiyt, for example, the mean duration of geminate /mm/ at the fastest rate is shorter than the mean duration of singleton /m/ in the slowest rate (geminate-fastest vs. singleton-slowest: 87 ms < 121 ms). This indicates that absolute duration cannot reliably distinguish singletons and geminates across all speech rates.

**Table 2:** Mean duration and standard deviation (ms) for singletons and geminates for two most extreme speech rates (fastest and slowest).

S01	Singleton		Geminate	
	Fastest	Slowest	Fastest	Slowest
	67 (20)	121 (19)	87 (9)	287 (25)
S02	77 (14)	115 (52)	132 (21)	263 (44)
	72 (6)	133 (43)	100 (12)	302 (40)
S04	108 (16)	134 (23)	133 (15)	208 (32)

### 3.4 Proportional ratio

As a consequence of this overlap at different speech rates, we looked at whether a proportional measure could provide a reliable way of distinguishing singletons and geminates. We applied - following previous work (e.g., Pind 1995, Hirata & Whiton 2005) - the ratio of /m/ and /mm/ duration to word duration (C/W), and observed that when this measure is plotted against speech rate (i.e., word duration) it allows for a rate-invariant boundary that distinguishes between the two categories. This is shown in Fig. 6, with the dashed black lines showing a possible optimal boundary for each language (i.e., if the C/W is below this line, the word almost certainly contains a singleton, and if it is above it almost certainly includes a geminate). Interestingly, this relational measure allows for classifying tokens as singletons or geminates for Finnish as well, even though it showed partly deviant patterns in both absolute durations and in speech rate manipulation.



**Figure 6:** Ratio of /m/ and /mm/ to word duration, as function of speech rate. Dashed line represents possible optimal boundary for each language.

The C/W ratio shows a remarkable similarity for the four languages, varying between 0.30 and 0.35 for Tashlhiyt, Japanese and Finnish, and slightly above 0.35 for Italian.

## 4. Discussion and conclusion

This study provided insights into how length contrast is acoustically implemented in four typologically unrelated languages. We aimed at determining whether the same invariant property reflects length contrast across different



speech rates in these languages. The analysis, based on a novel approach to speech rate manipulation, examined how rate affected different durational variables generally associated with gemination contrast.

Concerning adjacent vowels, results showed that they scaled differently with rate across languages, indicating differences in vowel-consonant interaction. In Tashlhiyt, Japanese, and Italian, rate effects on the preceding vowel were smaller before geminates than before singletons, while the interaction with the following vowel was similar across singletons and geminates. This shows that gemination affects the preceding vowel duration more strongly than the following vowel duration.

Importantly, an overlap was observed when the duration of /m/ and /mm/ were compared across the different speech rates. This is most notable when the durations of /m/ in slower rates are compared to the durations of /mm/ in faster rates. In this case, a singleton can even be longer than a geminate. Results also show that geminates are more affected by speech rate than singletons, with the biggest durational differences between singletons and geminates at slower rates. This result is in line with previous findings by inter alia Port et al. (1980), Pind (1995), and Hirata & Whiton (2005): when speech rate is slower, the differences in absolute durations between singletons and geminates are further enhanced with an important increase in geminate durations.

Despite the overlap of singleton/geminate durations, a relational measure reliably distinguished between the two categories. The C/W ratio allowed to accurately classify the singleton and geminate tokens, with a boundary at around 0.35. This boundary ratio is strikingly similar to the boundary reported by Hirata & Whiton (2005), which yielded a classification accuracy of more than 95% for Japanese. Taken together, these findings suggest that a relational measure could form the basis for an acoustic attribute of gemination that is rate-independent and language-independent.

The results of this study also provide some insight on how singleton and geminate durations are controlled. Large differences in rate-scaling of singletons and geminates demonstrate that consonant durations cannot be modeled as an intrinsic duration plus a global speech rate adjustment: some additional mechanism is needed to account for the scaling differences. Cross-linguistic variation, both in singleton and geminate durations and in the interactions with adjacent vowels, suggests that language-specific differences, including differences in the prosodic organization of syllables and words, are related to differences in the way length is controlled.

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