An Acoustic Analysis of Release Burst Amplitude in the Kelantan Malay Singleton/Geminate Stop Contrast

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Abstract
This study investigates whether the amplitude of release bursts is a potential cue to the word-initial singleton/geminate contrast in Kelantan Malay (KM). The voiceless stop series (/p-/pp/, /t-/tt/, /k-/kk/) were examined in two different utterance conditions. Results show that release bursts for geminate stops were produced with significantly greater energy than those for singleton stops, suggesting greater articulatory efforts to mark gemination. Although the effects of prosodic context and stop place of articulation were noticeable, significant amplitude differences were preserved across utterance contexts. The findings support the role of spectral parameters, in particular release burst amplitude, in enhancing the short/long consonant contrast in this Malay variety.

Index Terms: geminate, voiceless stops, release burst amplitude, Malay

1. Introduction
The singleton/geminate consonant contrast is usually defined in terms of length, i.e., geminate stops exhibit longer closure durations than their singleton counterparts (e.g., [1]). Studies on short versus long consonants, at least intervocally, have shown, however, that rather than being restricted to timing differences alone, there are additional non-durational correlates to the stop length contrast which include release burst amplitude. For example, in Finnish [2] and Malayalam [3], which have a singleton/geminate contrast like KM, burst amplitude for geminate stops is significantly greater than that for singleton stops.

One of the unusual typological features of KM is that geminates can only occur word-initially, and potentially utterance-initially. To this point, no work on burst amplitude has previously been conducted on KM or any variety of Malay with a short/long consonant contrast. In fact, the acoustic characteristics of word-initial geminates have not been subject to as much investigation as in medial position, especially in the case of burst amplitude in isolated tokens – one of the utterance contexts tested in this study. Previous investigation of burst characteristics in Pattani Malay [4], the Malay variety with which KM shares many phonological features, mainly focused on the amplitude of the first syllable of disyllabic words relative to the second syllable. The mean amplitude ratio of initial syllables beginning with geminate stops was found to be higher than that of initial syllables with singleton stop onsets. Given that stop closure for voiceless geminate stops cannot be a potential cue to the singleton/geminate contrast in utterance-initial tokens, we hypothesize that the amplitude of release burst may also serve as an important auxiliary cue to gemination in the same environment in KM.

In a number of related studies, initial strengthening has been observed in higher-level prosodic domains. In Cheju Korean [5], for example, it has been found that the intensity level of release burst is higher in prosodically strong positions, i.e., utterance-initial position, than in medial contexts. We therefore consider the possibility that the singleton/geminate consonant contrast in KM may also be affected by similar conditioning factors. In other words, the singleton/geminate contrast is also heightened in utterance-initial position due to potential domain-initial strengthening.

Previous findings for KM [6, 7, 8] have confirmed the roles of closure duration and VOT as sufficient acoustic markers for the short/long consonant contrast in utterance-medial contexts in KM, while post-consonantal vowel duration also shows some significant, albeit small, effects. By examining the spectral properties of release burst in greater detail, we extend these earlier results by determining whether the utterance-initial geminate articulation is (a) manifested in greater burst energy and (b) potentially associated with the singleton/geminate contrast in KM. These results will further increase our understanding of the word-initial stop length contrast in KM and possibly have important cross-linguistic implications for acoustic cues to consonant gemination.

2. Method
2.1. Materials
We conducted an acoustic phonetic experiment to examine the possible role of release burst amplitude in the singleton/geminate stop contrast in KM. The corpus is presented in Table 1.

Table 1. List of stimuli and their glosses.

<table>
<thead>
<tr>
<th>Word</th>
<th>Gloss</th>
<th>Word</th>
<th>Gloss</th>
</tr>
</thead>
<tbody>
<tr>
<td>/p/</td>
<td>/pitu/</td>
<td>/pp/</td>
<td>/ppitu/</td>
</tr>
<tr>
<td>/t/</td>
<td>/tido/</td>
<td>/tt/</td>
<td>/ttido/</td>
</tr>
<tr>
<td>/k/</td>
<td>/kibi/</td>
<td>/kk/</td>
<td>/kkibi/</td>
</tr>
</tbody>
</table>

The KM data in this study contained twelve tokens composed of six minimal pairs opposing singletons to geminates in two vowel contexts: high front vowel /i/ and low central vowel /a/. The singletons and geminates represent three types of voiceless stops: /p, t, k/. All tokens were disyllabic words with either C(C)V.CV or C(C)VCVC structures presented in two utterance conditions: utterance-initial and utterance-medial positions (see § 2.2 below).
2.2. Speakers and Data Collection

Sixteen KM native speakers, eight males and eight females, participated in the experiment. All of them had spent their childhood in the state of Kelantan, Malaysia, and no speaker displayed any other regional accent or any speech disorder at the time of recording. They were all university students, with a mean age of 24 years, and were paid for their participation. The recording took place in a professional studio in Melbourne (6 speakers) and a quiet room on the university campus in Kelantan (10 speakers).

In all sessions, speakers were instructed to read the tokens six times each in isolation and a carrier sentence. Each item was randomly presented on a computer screen in Standard Malay orthography. The carrier sentence /diɔ kɔtɔ (the target word) tigɔ kɔli/ (/he said (the target word) three times/) – adapted from [9] – was written down on a piece of A4 paper. The total data collected consisted of 2,304 utterances (6 singletons + 6 geminates x 2 positions x 16 speakers x 6 repetitions).

2.3. Data Analysis

The speech materials were segmented into single utterances for each speaker and annotated using the Praat software package [10]. Burst amplitude was measured in decibels in all tokens over the release duration of voiceless singleton and geminate stops. This duration was defined as the temporal interval between the onset of stop release and the onset of voicing of the following vowel. Spectral data were obtained using tkassp 2.0 in the database analysis software EMU-R [11] with a DFT of 256 points (5-ms Hamming window) and a sampling frequency of 44.1 kHz.

Initial inspection of the averaged spectra showed mirror-like distributions of energy between singleton and geminate stops at all frequency regions. As a consequence, we considered the sum of the energy in the entire spectrum over all frequencies (0 - 22 kHz) as the main acoustic parameter in this study. As shown by [12], the effects of consonant strengthening could be reflected in differences in acoustic burst energy over all frequencies. Values were calculated at the temporal midpoint of release for singleton and geminate stops.

For statistical evaluation, a mixed-effects model [13] was performed on the data using the lme4 package in the statistical package R. Fixed factors were Length (singleton or geminate), Position (utterance-initial or utterance-medial), Phoneme place of articulation (/p, t, k/) and Vowel (high front vowel or low central vowel). Speaker was treated as a random factor. The results of the mixed-effects model were further submitted to ANOVA summaries (see § 3 below).

3. Results

3.1. Overall Results

Results from a mixed-effects model (see Table 2) show that Length (F(1,2298)=197.80, p<.001), Position (F(1,2298)=24.201, p<.001), Phoneme (F(2,2297)=100.44, p<.001) and Vowel (F(1,2298)=27.666, p<.001) are all significant main factors in determining burst amplitude values. The two-way interaction between Length and Position is also highly significant (F(1,2296)=35.977, p<.001), suggesting prosodic influences (i.e. utterance position) on release burst energy. Although Phoneme and Vowel show significant main effects, there are no interactions between Length and Phoneme nor between Length and Vowel, suggesting consistent values of burst energy for singleton and geminate stops irrespective of place of articulation variation and vowel context.

### Table 2. Estimated coefficients, standard errors and associated z-statistics of fixed effects.

| Fixed effects          | Estimate | Std. Error | z-value | Pr(>|z|) |
|------------------------|----------|------------|---------|----------|
| (Intercept)            | 57.211   | 2.039      | 28.056  | <.001    |
| Length                 | -5.625   | 0.305      | -16.91  | <.001    |
| Position               | -2.049   | 0.305      | -5.83   | <.001    |
| Phoneme                | 6.933    | 0.373      | 17.015  | <.001    |
| Vowel                  | -2.184   | 0.305      | -6.235  | <.001    |
| Length x Position      | 4.729    | 0.652      | -17.31  | <.001    |
| Length x Phoneme       | -1.899   | 0.760      | -12.61  | 0.087    |
| Length x Vowel         | -0.088   | 0.659      | -12.16  | 0.929    |

In light of the strong main effect of Phoneme and the significant interaction between Length and Position identified above, the next sub-sections will focus on the burst amplitude results of singleton versus geminate stops according to utterance condition and phoneme type.

3.2. Consonant Length and Utterance Position

Figures 1 and 2 present the results of burst amplitude for all singleton and geminate stops in each utterance context. Detailed measurements are given in Table 3.
### 3.3. Consonant Length and Phoneme Identity

The amplitude of stop bursts separated by phoneme type is illustrated in Figures 3 and 4 below, while Table 4 reports the mean and standard deviation values of the energy sum.

![Figure 3: Distribution of energy sum (dB) of the entire spectra according to phoneme type.](image)

<table>
<thead>
<tr>
<th>Utterance-initial</th>
<th>Utterance-medial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singleton</td>
<td>Geminate</td>
</tr>
<tr>
<td>56 (10)</td>
<td>67 (11)</td>
</tr>
<tr>
<td>Singleton</td>
<td>Geminate</td>
</tr>
<tr>
<td>57 (11)</td>
<td>60 (13)</td>
</tr>
<tr>
<td>/p/</td>
<td></td>
</tr>
<tr>
<td>54 (8)</td>
<td>62 (9)</td>
</tr>
<tr>
<td>/t/</td>
<td></td>
</tr>
<tr>
<td>55 (8)</td>
<td>58 (9)</td>
</tr>
<tr>
<td>/k/</td>
<td></td>
</tr>
<tr>
<td>51 (8)</td>
<td>57 (7)</td>
</tr>
</tbody>
</table>

Table 4. Mean sum energy values (dB) of release bursts according to phoneme type. Standard deviations are indicated in parentheses.

![Figure 4: Averaged spectra of release bursts taken at temporal midpoint for singleton and geminate stops according to phoneme type.](image)
The results show that there is clearly an effect of phoneme length on the averaged spectra of release bursts in utterance-initial position, hence the increased separation between the two stop categories: singleton and geminate, in this utterance condition. Regardless of this potential effect of domain-initial strengthening in utterance-initial position, the singleton/geminate contrast is maintained across the three places of articulation in both utterance contexts, with geminate stops having a significantly greater sum of burst energy than singleton stops (p<.01). The energy sum distinguishing singleton and geminate stops is greatest for bilabials (mean difference: 11 dB) which also showed the greatest variability, followed by alveolars (mean difference: 8 dB) and then velars (mean difference: 6 dB) in utterance-initial position. In utterance-medial position, lower levels of burst energy are employed to mark gemination, with only a mean 3-dB difference between singleton and geminate stops at each place of articulation.

4. Discussion and Conclusions

In this study, we have examined the potential role of burst amplitude in the KM corpus by inspecting spectral characteristics of stop release bursts and their sum of energy that may separate singleton and geminate categories. Our results lead to a number of conclusions.

First, we investigated whether burst amplitude could be an additional cue to the contrast between word-initial singleton and geminate stops. The findings support our hypothesis: burst amplitude does vary significantly as a function of consonant length, with release bursts for geminate stops being significantly louder than singleton stops across utterance conditions. The fact that VOT duration in KM was found to be significantly shorter for geminates than for singletons (see [7]) may also reflect greater air pressure accumulated behind the constriction immediately before the release of geminate stops, resulting in faster release and greater burst energy. While our study is the first to specifically examine burst amplitude in a Malay variety, the current results also partially concur with earlier findings for the closely related variety Pattani Malay in that overall amplitude – which can be linked to release amplitude – is higher in initial syllables beginning with geminate stops [4]. In addition, differences in burst amplitude values found in the present study reach the suggested range of just noticeable difference (JND) value between 0.25 to 3 dB, depending on frequency regions [14]. These differences are therefore potentially a sufficient cue for listeners.

Second, in keeping with other studies that have explored the influence of prosodic domain-initial position on consonant articulation, we speculated that several conditioning factors, namely utterance position and phoneme type, might trigger some enhancement or diminution in the consonant contrast. The significant interaction found between phoneme type and utterance position appears to support domain-initial strengthening which has been the main focus in a number of studies on prosodic structures, e.g., [12]. As for the main effect of phoneme type, burst amplitude is always greatest for bilabials regardless of any context, this is in agreement with what has been established for the acoustic parameter of voice onset time (VOT), in that shortest VOT duration is generally shown in bilabials [15], implying fastest release and therefore greatest burst energy for this particular stop type.

Third, we discovered that, at least for the acoustic parameter measured in this study, release burst amplitude can be associated with the short/long consonant contrast in KM. This parameter appears to function as a domain-strengthening strategy, which is especially apparent for geminate stops, in order to compensate for the ambiguous nature of voiceless stop closures, given problems in establishing closure onset at the beginning of utterance-initial tokens. The strengthening pattern for geminate stops we found across experimental factors can be interpreted as the manifestations of more forceful articulations and can also be explained in terms of aerodynamic activity. This characteristic may well characterize geminate stops in the current corpus and is likely to add to the perceptual weight of the singleton/geminate distinction in KM. As to whether burst amplitude is a sufficient cue by itself, this question warrants further experimental investigation of the perception of the singleton/geminate contrast in KM.

In sum, the important role of release burst amplitude – alongside closure duration and VOT (see [6, 7]) – is evident in the KM corpus. Given the hypothesis (e.g., [2]) that temporal and non-temporal parameters may work together in signaling the length, and possibly strength, of gemination, future work will focus on the potential contributions of other non-durational correlates, e.g., F0 or formant transitions, on consonant gemination beyond the target consonants themselves and also in a wider range of prosodic contexts.

5. References

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