ARTICULATORY ORGANIZATION OF GEMINATES IN HUNGARIAN

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ABSTRACT

It is traditionally assumed that geminates undergo degemination when being flanked by another consonant in Hungarian. Since in Hungarian duration is considered to be the main acoustic cue to the singleton-geminate opposition, it appears valid to study phonetic implementation of this process in the acoustic domain. However, previous acoustic analyses lead to inconclusive results on the status of the "degeminated" consonant, while articulatory data on Japanese singletons and geminates imply that it is revealing to study degemination on the level of gestural timing.

The present study compared gestural organization of geminates, and degeminated, and singleton consonants in heterorganic C-clusters, and in intervocalic positions. We obtained EMA data from 10 female speakers of Hungarian (aged 27.7). Consonant duration, plateau durations and tongue rise showed that degemination does not yield realizations equivalent to intervocalic singletons, and geminates and singletons in clusters showed equally slower tongue rise than that observed in intervocalic singletons.

Keywords: geminate, degemination, articulation, gestural overlap, timing of tongue rise.

1. INTRODUCTION

Hungarian express semantic differences by using contrastive vowel and consonant phoneme length, see e.g., *kor* 'age' ~ *kór* 'illness'; *ép* 'healthy' ~ *épp* 'right now'. In theoretical works, duration is considered to be the main acoustic cue that makes the singleton-geminate phonological contrast in consonants. It is also traditionally assumed that geminates do not occur flanked by another consonant on either side, and that in these positions, geminates surface as short. This process is called degemination [17].

On the basis of acoustic data, pervious research concluded that in line with other languages that exhibit the contrast (see [14] for a review of geminate stops in 24 languages), it is indeed durational properties, especially closure duration, that are the most important correlates of the singleton-geminate opposition in Hungarian stops [8–11]. [19] showed that the pooled average duration of several different types of long/geminate consonants (measured in non-controlled environments) is approx. 160% of the average duration of the short/singleton consonants. Further, [10] also proposed that consonants having a complex internal structure, i.e., stops and affricates are lengthened in their middle portion if geminated, that is, they are lengthened in their closure phase. [10] based her claim again on acoustic data: she measured a ratio of 210% between the singleton and the geminate affricates' closure phase. [11] also analysed degemination cases in affricates (i.e., cases where the geminates were flanked by a consonant), and she found that the duration of degeminated affricates were approx. 110% of that of singletons (i.e., degeminated consonants may not be considered identical to singletons with respect to their total duration), and that the closure-to-total-consonant duration ratio in degeminated affricates was 9% higher than in intervocalic singletons, and 3% higher than in singletons flanked by another consonant. In a study on spontaneous speech, [8] showed that the ratio of the total duration of geminates and singletons is approx. 140-150% in Hungarian /p t k/, while in geminates, the closure-duration-to-total-consonant-duration ratio is greater than that observed in singletons only in approx. 10%. Lastly, [16] analysed some fricative and stop geminates in degemination cases, flanked by varying consonants. The authors revealed that due to the fact that correlates of bursts and realease phases were often missing from the acoustic signal, singleton and geminate stops were both very difficult to segment and analyse acoustically (especially in the studied contexts). Nevertheless, as far as stops are considered, they concluded that among degeminated and singleton /t/ and /p/ realisations, singletons (in C_1C_2, either as C_1 or C_2) were the longest, followed by degeminated geminates (flanked by a C_2 on one side), and singletons in $C_1C_2C_3$ sequences (as C_2 consonants).

In Hungarian, articulatory organization of consonant clusters, geminates, or degeminated consonants have not been analysed so far. In Japanese, however, a language that contrasts singleton and geminate consonants similarly to Hungarian, studies found that contact is maintained longer for geminate stops, and that the tongue also tends to move slower in geminates than in singletons, while the vowel preceding the geminate is also longer (see [4] and its references). The cited study draws attention to the interesting fact, that in Japanese, vowel lengthening before geminates signifies that, as opposed to most languages, there is no reciprocal relationship between vowel and the following consonant, and raises the question, if differences in vowel duration between singletons and geminates are merely a side effect of the slower tongue movement. As in the cited study only two speakers' data was analysed, and those showed divergent results, the authors could only tentatively conclude that the later occurrence of peak timing did not directly affect the length of the preceding vowel, which may thus have been affected by other factors.

In the present study we aimed to analyse some acoustic and articulatory features of singleton, geminate and degeminated stop consonants in Hungarian, in hopes of answering the questions, whether i) degemination neutralizes the singleton-geminate opposition in the acoustic and articulatory domain, ii) singletons in $\mathbf{C_1}C_2$ clusters, and geminates in degeminating $\mathbf{C_1C_1}C_2$ positions differ in the extent of articulatory overlap they exhibit with a following heterorganic consonant, iii) slower tongue rise and longer preceding vowel duration is observable in geminates (compared to singletons), and if they are independent of each other.

2. METHODS

2.1. Participants, material, and data recording

10 healthy native speakers of Hungarian participated in the study (all females, aged 27.7±6.44 years).

We analysed the voiceless alveolar /t/ and the bilabial /p/ in read speech as

- intervocalic geminates in V$\mathbf{C_1C_1}$V (gem), as in e.g, *kaze**tt**a* 'cassette',
- geminates in degeminating heterorganic C-clusters in V$\mathbf{C_1C_1}C_2$V (degem), as in e.g., *krike**tt**partin* 'cricket-match',
- intervocalic singletons in V$\mathbf{C_1}$V (sing), as in e.g., *vege**t**atív* 'vegetative', and
- singletons in heterorganic V$\mathbf{C_1}C_2$V clusters (singC), as in e.g., *szöve**t**papucs* 'carpet-slipper'.

Target sequences occurred word-internally in real words, in pre-verbal (accented) focus position of sentences, but as the coda and onset of the second and third unaccented syllables. Speakers read the sentences presented on a computer screen in a randomized order.

Although our main aim was to analyse only the effect of the above listed conditions, to increase variance in the data, we varied the vowel context and the place of articulation (POA) of consonants in a balanced fashion. That is, we included 3 vowel context conditions, V_{front}- V_{front}, V_{front}- V_{back}, V_{back}-V_{back}. and two types of POA order with respect to stops and stop clusters, $C_{bilabial}$(-$C_{alveolar}$), $C_{alveolar}$(-$C_{bilabial}$), but in most analysis, we did not include these factors as predictors in our statistical models, and used them only to increase jitter. The two exceptions were the following: we included POA in the gestural overlap analysis (see section 2.2), as coordination of labial and lingual consonants is expected to vary as a function of order, and we excluded labial consonants from the tongue rise analysis (see section 2.2), for the obvious reason that the relevant gestural plateau is not formed by the tongue but by the lips in these consonants.

We recorded (4 conditions × 3 V-contexts × 2 stop POA × 6 repetitions =) 144 tokens per speaker (1440 altogether), and after the exclusion of 2 tokens due to technical reasons, we analysed 1438 tokens.

Data recordings were carried out in a sound treated room using a Carstens EMA AG501 system. We recorded the upper and lower lip movements, and the tongue movements at tongue tip, tongue blade, and two points on the tongue dorsum.

2.2. Data processing and analyses

Head movement and bite plane corrections were done by the Carstens software, while further post-processing (3D-2D conversion, and production of Emu-compatible ssff tracks) was carried out by the custom made converter of the I*f*L Phonetik, University of Cologne. Segmental labelling of the audio signal was carried out semi-automatically using the BAS web services G2P [13] and MAUS [15]; for gestural labelling we used Emu [18]. Durational analysis was based on the audio signal, while for gestural analysis we used the displacement and velocity tracks of the sensors that corresponded to the place of articulation of the stops at hand: the gesture of bilabial /p/ was identified on the basis of the Euclidean distance signal of the upper and lower lips, and the corresponding velocity track, while the gesture of the alveolar /t/ was detected on the basis of the tongue tip sensor's movement and velocity signals. For the detection of the gestural plateau we used the procedure described in [3]. We detected and calculated the following measures:

- **duration of the consonant** (acoustics),
- **duration of the preceding vowel** (acoustics),
- **duration of the total C-cluster** (acoustics),
- **duration of gestural plateau** (articulation), for which plateau onset and offset were measured as 20% threshold points on the vertical velocity signal (see [3]),
- **gestural overlap** (plateau overlap) (articulation), calculated as a difference of C_2 plateau onset and C_1 plateau offset (see [3]), and
- **tongue rise** as measured from the preceding vowel's onset (acoustics) to the plateau onset,

similarly to [4] (articulation) (only for alveolar consonants).

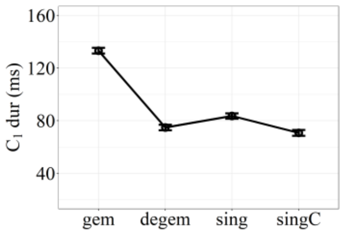
Data were analysed by Pearson's correlation method and linear mixed effect models in R [12], using the lme4 package [1]. *p*-values were obtained via the Satterthwaite approximation available in lmerTest package [6]. We included random intercepts for speakers. Post hoc analysis (Tukey test) was carried out by lsmeans package [7].

3. RESULTS

As far as duration data of C_1 obtained from the acoustic signal is considered, results are partly in line with expectation and previous data. On average, duration of geminates was 165% of that of the duration of singletons. However, duration of degeminated stops was a mere 88% of singletons, i.e., they were not longer, but shorter than those (as in [16], but as opposed to [11]), and degeminated stops patterned with singletons in clusters (Fig. 1).

Statistical analysis showed that condition had a significant effect on these data ($F(3, 1428) = 943.60$, $p < 0.001$), and that all groups differed from the others ($p < 0.05$).

Figure 1: C_1 duration obtained from the acoustic signal



Durations of the preceding vowel showed the trend observed previously also in Japanese, namely that vowels before geminate consonants were longer than those before singletons (Fig. 2). What is more, vowels before the C_1C_2 (singC) cluster were similarly long as those before C_1C_1 (gem), while vowels that occurred before degeminated long consonants and singletons were equally shorter.

We found a significant condition effect ($F(3, 1428) = 15.84$, $p < 0.001$), and all but the groups of C_1C_1 (gem) vs. C_1C_2 (singC) differed in the pairwise comparisons significantly ($p < 0.05$). Further, according to a Pearson's test, duration of V_1 and C_1 did have a significant, but very weak correlation ($r = 0.12$, $p < 0.05$).

Total duration of C_1C_1 (gem), and $C_1C_1C_2$ (degem), and C_1C_2 (singC) clusters also showed a significant condition effect ($F(2, 1065) = 20.48$, $p < 0.001$), and the post hoc analysis revealed that all three groups differ from one another ($p < 0.01$) (Fig. 3). It may be interesting to point out, that according to these data, geminates are significantly shorter than C_1C_2 clusters and thus may not be considered equivalent as suggested by [16].

Figure 2: V_1 duration obtained from the acoustic signal (all contexts)

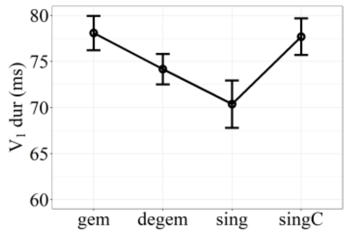
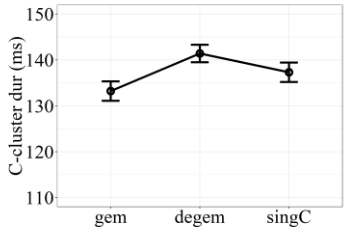


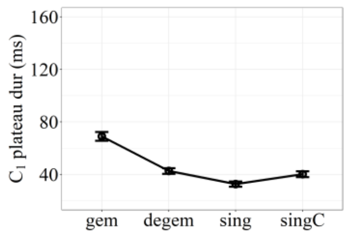
Figure 3: Total C-cluster durations obtained from the acoustic signal



As for the articulatory data, duration of stop plateaus (as articulatory correlate of closure) developed similarly to total stop durations, showing the longest durations for geminates, and equally shorter durations both for $\mathbf{C_1C_1}C_2$ (degem) and $\mathbf{C_1}C_2$ (singC). However, as opposed to C_1 duration data, gestural plateaus were the shortest for singletons (Fig. 4). In a way similar to the acoustic data of [10], duration of the closure phase of geminates was 233% of that of singletons, while degeminated geminates' closure was 133% of that of singletons in our data.

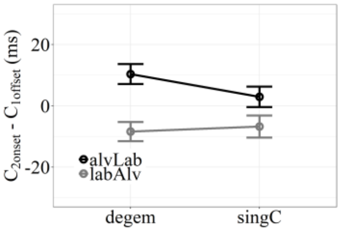
Statistical analysis revealed a significant condition effect ($F(3, 1411) = 211.36$, $p < 0.001$), and that in terms of C_1 plateau durations, all but the $\mathbf{C_1C_1}C_2$ (degem) and $\mathbf{C_1}C_2$ (singC) groups differed significantly ($p < 0.001$).

Figure 4: C_1 plateau duration obtained from the articulatory signals



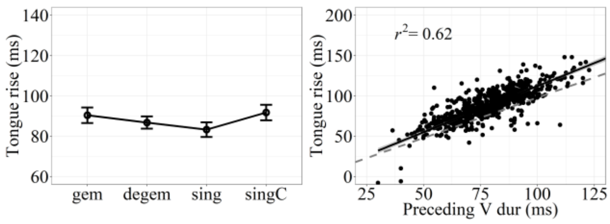
In the gestural overlap analysis of C_1C_1 and C_1 with the following C_2, we included the factor POA, as the overlap of a labial stop, followed by an alveolar stop is expected to be larger than that of the reverse order. As the significant interaction effect of POA and condition, and the following post hoc tests' results show, this was indeed the case, and the order of consonants did yield significantly different results as a function of POA order ($F(1, 705) = 8.55$, $p < 0.05$). However, the two test conditions differed only in the case of $C_{alv}C_{lab}$ vs. $C_{alv}C_{alv}C_{lab}$ (i.e., in the case of /tp/ vs. /ttp/) ($p < 0.05$), where the /tp/ cluster showed a greater degree of gestural overlap than the /ttp/ cluster, and not in the case of $C_{lab}C_{alv}$ vs. $C_{lab}C_{lab}C_{alv}$ (i.e., in the case of /pt/ vs. /ppt/), where the overlap of the neighbouring consonants in the cluster was similarly high in both conditions (Fig. 5).

Figure 5: Gestural overlap of $C_1C_1C_2$ and C_1C_2



Finally, the duration of tongue rise, i.e., the timing of the lingual movement form the preceding vowel onset to the onset of the gestural plateau (analysed only in alveolars) again showed a singleton in cluster (91±26 ms) ≳ geminate (90±26 ms) ≳ degeminated (87±20 ms) ≳ singleton (83±24 ms) order (from slowest to fastest) (sig. condition effect: $F(3, 1411) = 36.45$, $p < 0.001$) (Fig. 6, left). However, as revealed by the post hoc analysis in these data $\mathbf{C_1C_1}C_2$ (degem) and $\mathbf{C_1}C_2$ (singC) patterned together again, and this time, $\mathbf{C_1C_1}C_2$ (degem) did not differ from singletons (sing) either. (Only the comparisons of the pairs of gem vs. sing and sing vs. singC yielded significant results with $p < 0.05$.)

Figure 6: Tongue rise and its correlation with V_1 durations in alveolars



To test if longer V_1 durations (see Fig. 2) are the side effect of slower tongue rise in geminates and $\mathbf{C_1}C_2$ clusters, we carried out a correlation analysis of the data. Contrary to expectations one might have based on the claims of [4], we found that tongue rise in the consonant at hand, and duration of the preceding vowel are highly correlated ($p < 0.001$, $r = 0.78$) (Fig 6, right), and thus they may not be considered as independent as suggested.

4. DISCUSSION AND CONCLUSIONS

In this study we analysed several acoustic and articulatory features of singleton, geminate, and degeminated stops in Hungarian, to examine if i) degemination neutralizes the singleton-geminate opposition in the acoustic and articulatory domain, ii) singletons in $\mathbf{C_1}C_2$ clusters, and geminates in degeminating $\mathbf{C_1C_1}C_2$ positions differ in the extent of articulatory overlap they exhibit with a following heterorganic consonant, and iii) slower tongue rise and longer preceding vowel duration is observable in geminates (compared to singletons), and if they are independent.

Consonant duration and total consonant cluster duration as measured in the acoustic signal, and the duration of the gestural plateau detected in the articulatory signal unanimously showed that degemination do not reduce stops to intervocalic singletons, but rather to singletons that are flanked by another stop consonant (i.e., singletons in two-term clusters). Articulatory data further suggests that degeminated stops and two-term clusters form an in-between category between geminates and singletons. As far as the timing of the articulatory gestures, more specifically, the articulatory overlap of gestural plateaus is considered, we found that two-term clusters and degeminated stops differed only in lingual-labial (/pt/ ≠ /ppt/), but not in labial-lingual (/tp/ ≈ /ttp/) clusters, that is, degemination reduced geminates to singletons in C-clusters dependently of the place of articulation of the stops. Further, our results supported the findings of [4] showing that preceding vowel does not show shortening but lengthening before geminates. However, we also found the same trend for simple C1C2 clusters. Moreover, we found a similarly slow tongue rise for both geminates and singletons in two-term clusters, which suggests that in some aspects, the phonetic implementation of geminate stops resembles that of two-term stops clusters. And finally, we found a strong correlation of tongue rise and preceding vowel duration, suggesting that preceding vowel duration may very well be considered a mere side effect of the slower tongue movement in geminates and two-term clusters. This finding does not corroborate the tentative hypothesis of [4], and points to the fact the increase in vowel duration before geminates and C-clusters is in close connection to the decelerating articulatory gestures of the stop consonants. However, results for e.g., Italian and Norwegian [5] revealing shortening of the preceding vowel pose a challenge to this interpretation, and warrant for further research.

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