GEMINATE TYPES AND THEIR ACOUSTIC EFFECTS ON ADJACENT VOWELS IN HUNGARIAN

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ABSTRACT

The present study examines how phonologically different geminates (i.e., lexical, assimilated, and concatenated types) are implemented phonetically in Hungarian, with particular attention to the temporal and spectral parameters of the adjacent vowels. By investigating geminates in two positions (word-internally and at word boundary), the influence of boundary on geminate production is also observed. Results show that differences in the autosegmental representation of geminate types are mirrored in the durational and amplitude features of the consonants themselves and their neighbouring vowels. Moreover, the temporal properties of geminates seem to be affected by boundary type. However, formant frequencies of adjacent vowels did not show consistent change depending on geminate types. Findings shed more light on the relationship between abstract phonological categories and continuous phonetic details.

Keywords: consonant length, geminate types, vowel acoustics, autosegmental representation, Hungarian

1. INTRODUCTION

Many genetically unrelated languages use consonant length contrastively (e.g., Bengali [12], Hungarian [5, 15], Italian [7, 17], Japanese [8], Tashlhiyt Berber [7, 19]). Previous studies were consistent in reporting significant durational differences between singletons and geminates ([19] and the references listed there). With respect to other potential attributes of length, such as preceding vowel duration, VOT, f0, or amplitude, findings are not as consistent across languages [8, 12, 16, 19]. Therefore, it is claimed that the primary acoustic correlate of geminates is the increased duration of the closure or constriction. This supports the representation of the autosegmental framework (e.g., [14]), i.e., differences between singletons and geminates are represented as differences on the timing tier: one vs. two timing slots, respectively. However, the 'geminate' category is not homogeneous in the sense that it groups together long consonants derived from different sources phonologically. The autosegmental approach allows distinguishing three geminate types with different underlying representations, as illustrated on Fig. 1. Lexical geminates are part of the phonemic inventory of a language. Assimilated geminates derive from assimilatory processes, e.g., voicing assimilation. Concatenated ("fake") geminates are merged sequences of identical consonants.

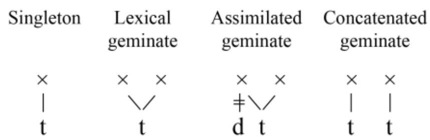

Figure 1: The autosegmental representation of singletons and three geminate types.

Studies dealing with the durational features of geminate types have yielded inconclusive results across languages, potentially reflecting language-specific characteristics, e.g., [9, 12, 17, 19].

No significant differences were found between the three above-mentioned geminate types in preceding vowel duration, closure duration and VOT in Bengali stops [12]. Geminate types did not differ in consonant duration; however, they differed in the duration of the preceding vowel in Libyan Arabic [9] and in Tashlhiyt Berber [19]. In contrast, durational differences in the geminates themselves were found in Italian [17] with concatenated geminates being produced longer than lexical ones.

The differences found between geminate types may be related to the position of the geminates analysed. In languages that do not use consonant length as a distinctive feature but fake geminates occur across morpheme boundaries, via affixation, in compounds or across word boundaries (like in English or German), it was observed that word-boundary geminates were frequently pulled apart in careful speech via f0 changes and pause insertion [2, 10, 16]. It is assumed that differences between geminate types may be due to the boundary-dependent lengthening process in case of fake geminates [16]. Assuming that the boundary strength is not a binary (as in SPE phonology: strong/'word', or weak/'morpheme' boundary [4]) but a gradual property, it was found that the more segmentable the prefix the longer the consonant duration [2]. The question arises whether boundary types have an influence on the secondary acoustic correlates of gemination (e.g., adjacent vowel duration) as well.

Hungarian is promising ground for investigating this question since it is an agglutinative language with various geminate types occurring at different boundaries in a variety of vowel contexts. Although the durations of geminate types have been examined under uncontrolled conditions (spontaneous speech) in Hungarian [15] and results indicated differences in the consonants themselves (showing short lag VOT as irrelevant in length contrast), secondary acoustic correlates have not been investigated so far. The present study examines the phonetic correlates of geminate types with particular attention to the surrounding vowel context in controlled material. It is hypothesised that (i) different geminate types show durational and/or spectral dissimilarity; (ii) the position/boundary type has an influence on geminate production, resulting in the same geminate type being articulated differently at morpheme boundary within a word than across word boundaries (e.g., indicating the word boundary by incomplete neutralization in voicing assimilation or by pulling the segments apart in concatenation).

2. METHODS

The research material consisted of singletons (S), lexical geminates (Glex), assimilated geminates (Gass) and concatenated geminates (Gcon). The latter two types appeared in two positions: word-internal (WI) and at word-boundary (WB). WI geminates arose from consonant sequences that span a morpheme boundary within a word (root+suffix, weak boundary), whilst WB geminates appeared at the connection of two lexical free morphemes composing a phrase (word#word, strong boundary).

For each geminate type we chose meaningful words/phrases where the target sounds occurred in the same vowel context. For frequency and distributional reasons, the consonant type under study was the (short/long) voiceless alveolar stop [t], and the preceding and following vowels were [ɒ] or [ɛ]: identical V1 and V2 in the VCV sequences. The target words were embedded in 12 sentences as the first words of the sentences, either in preverbal focal position or as verbs of the sentence (Table 1). Word-level stress is highly predictable in Hungarian; always assigned to the initial syllable of a prosodic word [21]. The segments we studied occurred in unstressed syllables except for word-boundary geminates, which concern the first syllable, thus, prosodic effects cannot be ruled out. However, stress tends to affect intensity rather than duration, whereas lengthening may serve as vowel and consonant quantity distinction is this language.

Types	Sentences	Glosses
S	Köve**t**elem [køvɛtɛlɛm] a pénzem.	I demand my money.
Glex	Helye**tt**esít [hɛjɛtːɛʃiːt] a matektanár.	The math teacher substitutes.
Gass WI	Enge**dt**elek [ɛŋgɛtːɛlɛk] téged is vezetni.	I let you drive too.
Gass WB	Neke**d** **t**eszek [nɛkɛtːɛsɛk] szívességet.	It's you I'm doing a favour for.
Gcon WI	Éle**tt**elen [eːlɛtːɛlɛn] volt a bolygó.	The planet was lifeless.
Gcon WB	Néme**t** **t**ervek [neːmɛtːɛrvɛk] voltak a táskában.	German blueprints were in the bag.

Table 1: Example sentences ([ɛ] context).

The linguistic material was read aloud in three repetitions by twenty monolingual, Hungarian-speaking adults (10 males and 10 females, aged between 21 and 54 years, mean: 36.7±5 years). None of them reported any speech or hearing disability. Sentences were displayed to participants in random order on a screen using SpeechRecorder [6]. Speakers were instructed to read the sentences in their normal (not careful) speaking style [11]. The experiment was run in a sound-proof booth. The acoustic data were recorded at a sample rate of 44.1 kHz and 16-bit resolution. A total of 720 tokens were collected (12 sentences × 3 repetitions × 20 speakers). The following temporal and spectral parameters generally associated with gemination [7, 8, 19] were analysed using Praat [3]:

- Closure duration (CD, ms): The closure phase was measured between the termination of the preceding vowel and the stop burst.
- Duration of the preceding (V1) and following (V2) vowel (ms): The segmentation of the vowels was based on their second formants supported by visual analysis display of the spectrograms and oscillograms.
- CD/V1 and CD/V2: Closure duration related to preceding and following vowel duration.
- Relative RMS amplitude: A proportional variable measured as the root-mean-square amplitude of the stop release compare to the RMS amplitude of the following vowel.
- First two formants of adjacent vowels (Hz): F1 and F2 were extracted at the temporal midpoint of the vowel using the built-in Burg algorithm in Praat.

The raw data were standardised within speakers using *z*-transformation (for the statistical analysis). Linear mixed models were computed in R [18], using the lmer [1] and lmerTest [11] packages. The dependent variables were the above-mentioned acoustic parameters; the fixed factor was *geminate type* (including the three geminate types and the two positions), while the random factor was *speaker* (N = 20). *Vowel quality* was incorporated as fixed factor in the models on amplitude and formant frequencies. The effect of *gender* contributed no improvement to the models and was thus excluded during model selection. Pairwise comparisons with Tukey method were performed with emmeans [13]. F-values and corresponding *p*-values were computed using the Satterthwaite method. Plots were made with the ggplot2 package [23], also containing the singleton category as reference.

3. RESULTS

Besides the typical single-articulated, lengthened geminate realisation, rearticulated geminates occurred in 2.3% of the cases. These were produced solely at word boundary (5 assimilated and 9 concatenated geminates by five participants). (These occurrences were excluded from the CD measurements due to two closure phases.)

3.1. Absolute duration

As expected, the average **closure duration** of each geminate type was longer than that of singletons (Fig. 2). The statistical analysis revealed that closure duration was significantly affected by geminate type: $F(4, 586) = 28.968$; $p < 0.001$. For both derived geminate types, position influenced the durations in such a way that word-internal geminates were realised shorter and word-boundary ones longer, on average; however, the difference was not significant ($p > 0.05$).

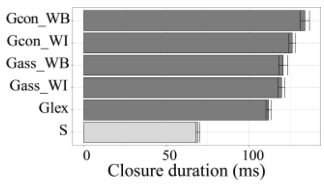

Figure 2: Closure duration of singletons and various geminate types (mean and standard error).

Concerning the **duration of the preceding vowel** (Fig. 3), a significant main effect of geminate types was shown: $F(4, 600) = 26.189$; $p < 0.001$. The V1 before lexical geminates was significantly shorter than V1 before any other geminate types except for Gass_WB ($p < 0.001$ in the three cases). The assimilated geminates did not differ between the two positions, but concatenated ones did ($p < 0.001$).

Geminate type had a significant effect on the **duration of the following vowel** as well (Fig. 3): $F(4, 600) = 337.56$; $p < 0.001$. V2 was realised with significantly longer duration after word-boundary geminates compared to word-internal ones ($p < 0.001$). Consistent differences by boundary types provided evidence for the manifestation of prosodic hierarchy by fine-grained phonetic details. The remarkable difference between the two WB geminates suggests that word-initial lengthening has a stronger effect on vowel duration after sequences of identical consonants than after assimilated geminates (which presumably pull the words together).

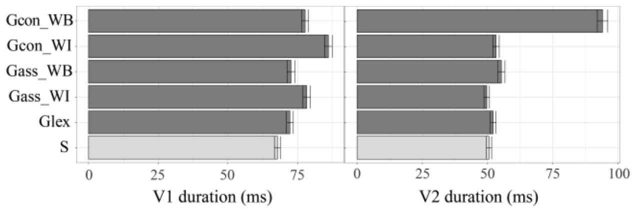

Figure 3: Preceding and following vowel duration as a function of geminate type (mean and standard error).

3.2. Relative duration

The **CD/V1** was higher for all geminate types than for singletons (in which the mean value was 1, indicating that the consonant and the vowel had the same duration, on average). The mean CD/V1 values were the same for the three word-internal geminates (1.5 in each case), but higher for the word-boundary geminates (1.6±0.3 for Gass and 1.7±0.5 for Gcon). Statistical analysis indicated that only Gcon_WB was significantly different from all the word-internal geminates ($p \leq 0.005$ in each contrast). The mean **CD/V2** was higher (2.2-2.5) for most geminate types than for singletons (1.4±0.4), except for the Gcon_WB (1.4±0.3). Statistical analysis showed that geminate types differed in this parameter: $F(4, 586) = 89.751$; $p < 0.001$.

3.3. Spectral parameters

Statistical analysis showed a significant effect of geminate type ($F(4, 586) = 8.878$; $p < 0.001$) and vowel quantity ($F(4, 586) = 18.427$; $p < 0.001$) on **relative RMS amplitude**. The [ɒ] vowel showed higher mean values than [ɛ], but the pattern by geminate type was the same for the two vocalic contexts. Pairwise comparisons confirmed that lexical geminates were realised with significantly higher amplitude than word-internal assimilated ones ($p = 0.004$) and word-boundary concatenated ones ($p < 0.001$). Furthermore, there was a significant difference between the two types of derived geminates at word boundary ($p = 0.024$). Same types of geminates did not differ in amplitude depending on the boundary type.

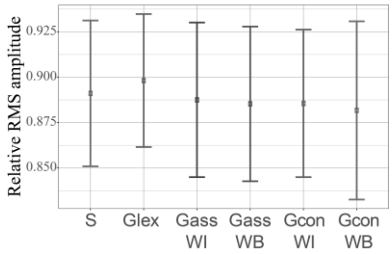

Figure 4: Relative RMS amplitude (mean and standard error).

Concerning the **formant frequencies of the preceding vowel**, a significant interaction effect of geminate type and vowel quality was found on F1 ($F(4, 600) = 34.252$; $p < 0.001$) and on F2 ($F(4, 600) = 6.088$; $p < 0.001$). This indicates that the change in F1 and F2 by geminate types was different depending on the vowel: Larger differences between geminate types were observed in the case of [ɛ] than in [ɒ]. Moreover, F1 values varied more widely than F2 values as a function of geminate types (Fig. 5). F2 values remained mostly unaltered regardless of geminate type.

Turning to the **following vowel** (Fig. 5), a similar picture was shown as in V1. Formant frequencies varied strongly with type of the geminate in [ɛ], but not in [ɒ] – in accordance with the significant interaction of geminate type and vowel quality in F1 ($F(4, 600) = 33.967$; $p < 0.001$) and F2 ($F(4, 600) = 21.624$; $p < 0.001$). In sum, [ɛ] appeared with higher F1 values in the lexical and assimilated geminate context than in the concatenation geminate context.

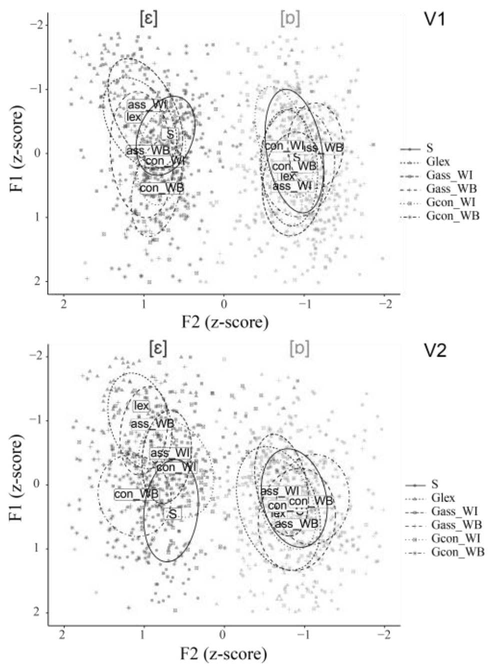

Figure 5: Formant frequencies of the preceding and following vowels as a function of geminate type.

4. DISCUSSION AND CONCLUSION

This study examined how phonological representations of geminate types are reflected in phonetic data. Besides the three commonly studied geminate types [9, 12, 19], we distinguished between types based on position to explore possible boundary-dependent and/or prosodically conditioned realisations [2, 16, 20].

Our first hypothesis was confirmed by the data, showing that the type of geminate significantly affects closure duration, adjacent vowel duration, relative duration and amplitude. Durational results are consistent with those found in Italian [17] (a syllable-timed language, like Hungarian), indicating that lexical geminates are realised with shorter duration than post-lexical ones. V1 and RMS results are in line with those found in Tashlhiyt Berber [19], showing that lexical geminates are produced with higher burst energy and with shorter V1 compared to concatenated ones. The frequencies of the first two formants of adjacent vowels did not show consistent change depending on geminate types. F1 variation by geminate types implies that their difference might be associated with the vertical movement of the tongue during adjacent vowel production. However, it is not uniform across vowel qualities and may be affected by prosodic factors or by the place of articulation of the other adjacent consonants. There may also be a non-local gemination effect, but more research is needed to understand this phenomenon in Hungarian, as previous studies suggests language-specific articulatory mechanisms in this respect [22].

As for the second hypothesis, results confirmed that the temporal properties of geminates are affected by boundary type. Even geminates of the same type were realised differently depending on whether they occurred at a weak/morpheme boundary (WI) or a strong/word boundary – in agreement with the results for English fake geminates [16]. Word-boundary concatenated geminates differed consistently from other geminates and exhibited longer CD, longer V2, higher CD/V1 ratio, lower CD/V2 ratio, and lower RMS amplitude. In some cases, word boundary blocked full assimilation in derived geminates by pulling the segments apart. These findings indicate a stronger coherence of articulation within words than across word boundaries, similarly to what was observed in case of two-term consonant clusters [20]. These findings may contribute to a better understanding of the relationship between distinct phonological categories and continuous phonetic variables, and shed more light on the role of morphological structure and prosodic factors in gemination.

5. REFERENCES

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