Acoustic correlates of the nasal vs. plosive quantity contrast in Hungarian

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Abstract

This study investigates the phonetic realization of consonant length in Hungarian. It is hypothesized that spectral structure differences between obstruents and sonorants may lead to distinct strategies in expressing quantity contrast. To test this hypothesis, intervocalic nasals (/n ɲ/) and plosives (/t k/) were analyzed in spontaneous speech from 20 monolingual Hungarian-speaking adults. Linear mixed-effects models and decision trees were applied to explore the effect of quantity, consonant type, and their interaction on various acoustic parameters, such as the durations of the target consonants and neighboring vowels, relative durations, and geminate-to-singleton ratio. Our findings indicate that nasals require more robust adjustments compared to plosives in the realization of the consonant length contrast. This study contributes to the understanding of phonetic variation in Hungarian and the distribution of geminates across languages.

Keywords: speech production, consonant length, nasal, stop, Hungarian

1. Introduction

Length serves as a distinctive feature between two sets of consonants, namely singletons and geminates, in a variety of languages. Previous research has demonstrated that a range of durational and non-durational acoustic parameters play a role in contributing to the quantity contrast, although the extent of their influence varies across languages (e.g., Al-Tamimi & Khattab 2018; Amano *et al.* 2021; Hermes *et al.* 2020). It is claimed that the primary acoustic correlate of geminates is the increased duration of the closure or constriction. However, findings concerning other potential attributes of length, such as preceding vowel duration, voice onset time, fundamental frequency, or amplitude, are not consistent across languages (Al-Tamimi & Khattab 2018; Lahiri & Hankamer 1988; Ridouane 2010).

Furthermore, the realization of consonant length may vary across consonant types. Different features are expected to contribute to the expression of quantity in obstruent vs. sonorant consonants, given their distinct spectral structures, for instance, their spectral continuity. Listener perception seems to differ depending on the consonant type, with short/long pair discrimination being more challenging in nasals than in obstruents (Kawahara & Pangilinan 2017).

In Hungarian, geminates can occur in all consonant types, including, but not limited to, nasals and plosives. This provides an ideal context for investigating the quantity contrast according to the consonant type. Until now, investigations into length contrast have concentrated on Hungarian plosive consonants (e.g., Deme *et al.* 2018; Neuberger 2023). No study has yet undertaken a comparison across different types of consonants in this regard.

The aim of this study is to explore the acoustic parameters contributing to the length opposition in Hungarian nasals and plosives. We hypothesize that speakers mark the contrast differently depending on the consonant type. Given the challenge spectral continuity poses to perceiving length contrast, it is plausible that speakers use the durational parameter more robustly in expressing nasal quantity contrast than plosive quantity contrast or enhance the nasal quantity contrast with additional secondary acoustic features.

2. Methods

Intervocalic nasal /n ɲ/ and plosive /t k/ singletons and geminates (N = 427) were collected from the spontaneous speech of 20 monolingual Hungarian-speaking adults (10 males) using the BEA database (Neuberger *et al.* 2014). The number of singleton and geminate consonants was quasi-balanced within each consonantal category. There was an attempt to exclude variation due to phonetic factors. Specifically, words containing target segments were selected to have a syllable count ranging from 2 to 4, while excluding initial and final segments. Regarding geminate types (see Ridouane 2010; Neuberger 2023), only lexical and word-internal assimilated geminates were considered, with concatenated geminates being excluded from the analysis. Surrounding vowels were short /ɒ ɛ o/.

The following acoustic parameters were measured by means of Praat (Boersma & Weenink 2020):

- Absolute duration of the target consonant (C): total duration of nasals and plosives (including closure duration, burst and release phase, i.e., voice onset time in case of voiceless plosives).
- Absolute duration of the preceding (V1) and the following vowel (V2): The segmentation of the vowels was based on their second formants supported by visual analysis display of the spectrograms and oscillograms.
- Relative duration of consonants and vowels (C/V1, C/V2): duration related to preceding and following vowel duration.
- Geminate-to-singleton ratio (G/S): durational ratio calculated by each consonant and by each speaker.

Instead of the raw durations, we used the logarithmic values of the absolute consonant and vowel durations because it is suggested that logarithmic durations are relational invariant acoustic variables that can cope with the durational variations of singleton and geminate consonants in a wide range of speaking rates (Amano *et al.* 2021).

Linear mixed-effects models (lmer and lmerTest packages: Bates *et al.* 2014; Kuznetsova *et al.* 2017) were constructed using R (R Core Team 2018) for each acoustic parameter to investigate the effect of quantity (singleton vs. geminate), consonant type (nasal vs. plosive) and their interaction. The random factor was the speakers (N = 20). 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 (Lenth 2018). F-values and corresponding p-values were computed using the

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Satterthwaite method. Plots were made with the ggplot2 package (Wickham 2016).

Additionally, decision trees were employed to identify the most important features in distinguishing the two phonological length categories in nasals and plosives. The models were trained on the following variables: logCdur, logV1dur, logV2dur, C/V1, C/V2. Decision trees were constructed using scikit-learn 1.4.2 in Python (Pedregosa *et al.* 2011).

3. Results

Our results indicated significant differences in the consonant duration between singletons and geminates in both nasals and plosives (see Figure 1). A significant interaction between consonant quantity (S vs. G) and consonant type (nasal vs. plosive) on consonant duration was observed: $F(2, 426) = 9.836$; $p = 0.002$. According to the Tukey post-hoc analysis, statistically significant differences were observed between nasals and plosives for both singletons and geminates ($p < 0.001$ in both cases). Nasals were produced with significantly shorter durations compared to plosives.

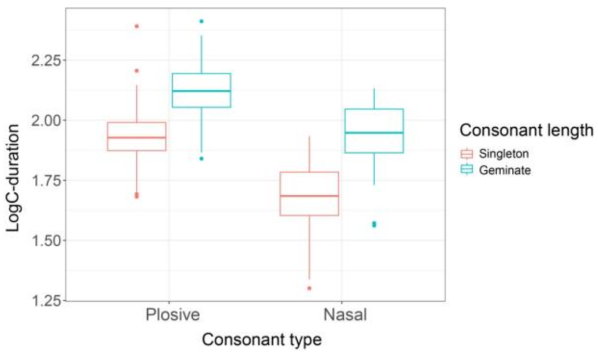

Figure 1: *Consonant duration (log-transformed) as a function of consonant length and consonant type.*

The G/S ratio was significantly higher for nasals compared to plosives, indicating a more distinct contrast in nasals. On average, it was 1.89 (±0.4) for nasals and 1.57 (±0.1) for plosives.

Preceding vowel duration (V1) showed discrepancies between nasal and plosive quantity contrasts (Figure 2). A significant interaction between consonant quantity and consonant type on V1 duration was observed: $F(2, 426) = 25.338$; $p < 0.001$. Vowel duration varied depending on the following consonant type. V1 was longer before nasal geminates compared to nasal singletons. This difference, however, was not observed with plosives, as V1 durations exhibited similar patterns before both singletons and geminates.

The duration of the following vowel (V2) differed significantly between plosives and nasals ($F(2, 426) = 6.431$; $p = 0.011$) but consonant length did not have an effect on this variable (Figure 3). Vowels following nasals were longer then after plosives, on average. To sum up, acoustic results also showed that the duration of the surrounding vowels helps distinguish the two phonological categories, with a greater contribution shown for nasals. The duration of the following vowels showed an opposite trend according to consonant type: for plosives, it was shorter after geminate than after singleton, while for nasals it was the other way round, longer after geminate than after singleton.

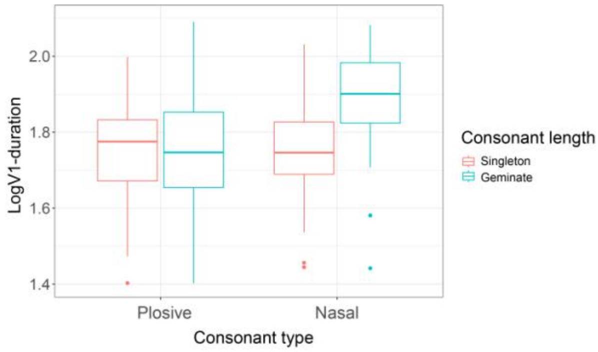

Figure 2: *Preceding vowel duration (log-transformed) as a function of consonant length and consonant type.*

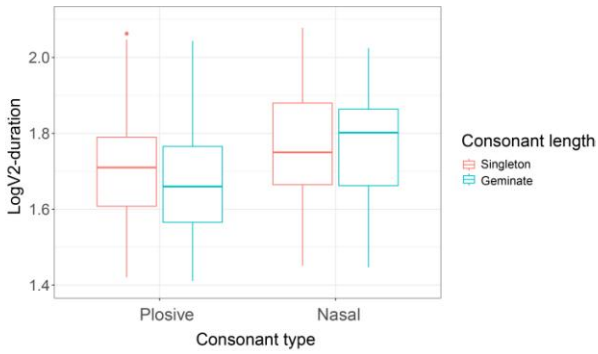

Figure 3: *Following vowel duration (log-transformed) as a function of consonant length and consonant type.*

Considering relative durations, a significant interaction between consonant quantity and consonant type on the ratio of consonant and preceding vowel duration (C/V1) was observed: $F(2, 426) = 13.414$; $p < 0.001$. In terms of this parameter, nasals and plosives differed significantly both for singletons ($p = 0.001$) and geminates ($p < 0.001$). Based on the Tukey post-hoc analysis, a statistically significant difference between singletons and geminates was identified exclusively for plosives ($p < 0.001$), whereas no significant contrast was observed for nasals in this parameter (Figure 4).

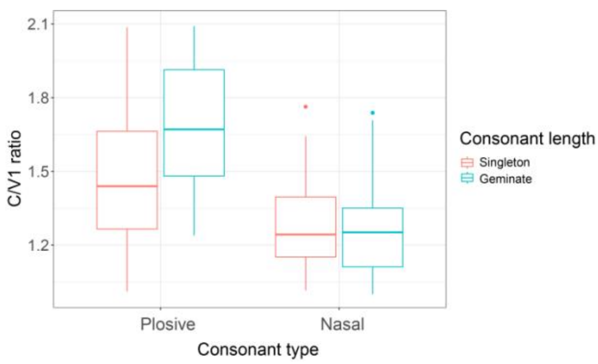

Figure 4: *Consonant-to-preceding vowel duration ratio as a function of consonant length and consonant type.*

Similarly, a significant interaction between consonant length and type was found in the ratio of consonant to following vowel duration (C/V2): $F(2, 426) = 5.273$; $p = 0.022$. Singletons differed from geminates in this parameter both for nasals and plosives ($p < 0.001$ in both cases). The average values were higher in case of geminates compared to singletons (Figure 5).

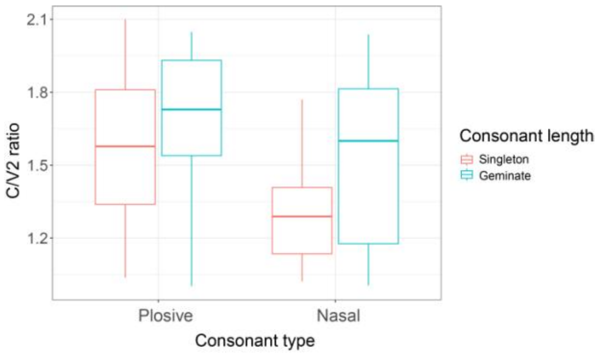

Figure 5: *Consonant-to-following vowel duration ratio as a function of consonant length and consonant type.*

In the next step, decision trees were applied to evaluate the contribution of each feature in reducing uncertainty associated with the target variables, thus aiding in the discrimination of the two quantity categories. The results show that for plosives, the two categories were distinguished primarily by consonant duration, while for nasals, the duration of the surrounding vowels also played an important role in addition to the consonant duration (Figure 6). Of the two relative durations, C/V2 seemed to be one of the more important features for both consonant types. C/V1 is less distinctive between the two quantity categories and may play a role more in plosives.

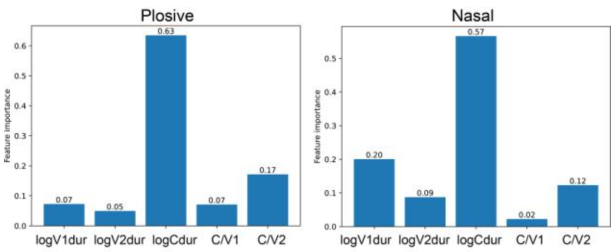

Figure 6: *Feature importance in distinguishing singletons and geminates in plosives and nasals.*

4. Discussion and conclusion

This study examined how the phonological quantity contrast of different consonant types is reflected in phonetic data. Our hypothesis was confirmed by the data, showing that speakers mark the contrast producing different durational patterns depending on the consonant type (nasal or plosive).

Our findings suggest that the expression of the quantity contrast in nasals requires more robust time adjustments than in plosives. In general, nasal consonant exhibited shorter durations in comparison to plosives. The relatively short durations may make the difference between short and long nasals less noticeable. Consequently, it is conceivable that supplementary features, such as the duration of surrounding vowels, play a role in marking the length contrast.

Results of the present study reflect the previous finding (see Kawahara & Pangilinan 2017) that listeners have more difficulty distinguishing the length contrast in spectrally continuous sounds (like nasals), and therefore speakers put more effort into their production to ensure successful comprehension. More specifically, there were differences in adjacent vowel durations depending on whether the following consonant was a nasal or a plosive. In Hungarian, the vowel preceding the target consonant (V1) seemed to be produced significantly longer before nasal geminates than before nasal singletons. However, this distinction was not evident with plosives. In future research, perceptual ratings on the data of the present corpus can help us establish whether the results found for Japanese can be applied to Hungarian.

The results of this study contribute to a more accurate description of the phonetic realization of phonological length in Hungarian, and may bring us closer to understanding the preferential hierarchy of geminate occurrences across languages, namely that obstruent geminates are more likely to occur in a language than nasal geminates. To enhance our understanding of this phenomenon, in forthcoming investigations, we intend to conduct spectral analyses on the adjacent vowels.

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