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# German and Hungarian long and short vowels in fast speech

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## Abstract

At faster speech rates, segments are generally expected to be produced shorter, but not every segment may be compressed to the same extent. In both German, and Hungarian we find phonologically distinctive vowel length contrast which is expressed using different combinations of durational and spectral cues. In fast speech, temporal reduction is also expected to be accompanied by some degree of spectral reduction due to target undershoot. As a result, increased speech rate is assumed to endanger the vowel length contrast in both the temporal and the spectral domains of speech. In the present study, we tested this hypothesis and explored whether contrast reduction manifests differently in the two typologically unrelated languages mentioned above. We analyzed the duration of vowels and the duration ratio, and spectral distance in the $F_1 \times F_2$ plane of the short-long vowel pairs produced by 15 Hungarian and 14 German speaking females. Results showed that, in general, both durational and spectral cues of the quantity contrast were preserved. Hence, the quantity contrast was maintained in fast speech in both languages, suggesting that neither durational nor spectral cues of the contrast may be considered redundant.

**Index Terms**: speech rate, vowel length contrast, fast speech, vowel quantity, Euclidean distances

## 1. Introduction

Fast speech is the result of speech sounds produced shorter. Therefore, at faster speech rates, both vowels and consonants are expected to be generally shorter or, in other words, more compressed, compared to those we find in slower or comfortable speech rates. However, empirical evidence suggests that vowels and consonants are not reduced to the same extent in duration, as vowels in general may be compressed more than consonants in fast speech [1, 2, 3, 4, 5]. Furthermore, it is also expected that not every segment may be compressed to the same extent within the group of vowels, especially if duration serves linguistic functions, as in, for instance, German, and Hungarian. In these languages, vowel length contrast is phonologically distinctive which means that we find minimal pairs like *Schal* [ʃaːl] 'scarf' vs. *Schall* [ʃal] 'noise' in German, and *kár* [kaːr] 'damage' vs. *kar* [kɒr] 'arm' in Hungarian.

In Hungarian, phonologically short and long high vowels, for instance, /i iː/ and /u uː/, are traditionally assumed to be distinguished primarily by duration, while short and long low vowel pairs /ɒ aː/ and /ɛ eː/ differ also in their quality (as reflected clearly by the IPA notation as well) [6]. In German, the situation is the other way round: (in accented syllables) we find no quality difference between the low vowels /a/, and /aː/, while there is a simultaneous durational and quality difference in high vowel pairs, for instance, in /ɪ iː/ and in /ʊ uː/ [7].

In vowels, temporal reduction caused by fast speech is also expected to be accompanied by some degree of spectral reduction as well, due to target undershoot [8, 9]. As a result, increased speech rate is assumed to endanger the vowel length contrast in both the temporal and the spectral domains.

To this hypothesis, we find scarce, and to some extent, inconclusive evidence in Hungarian and German. With respect to segmental duration, in Hungarian, there is a growing body of evidence showing that long vowels reduce to a higher degree than short vowels [4, 10, 5]. Similarly, in German, long (tense) vowels were found to reduce more than short (lax) ones [7].

In terms of vowel quality, both short and long vowel spaces in German were found to be affected by fast speech in a similar manner: they were either reduced or, contrary to expectations, increased in different dialectal regions compared to normal speech [11]. Since the analysis of [11] did not specifically cover spectral distinction of vowel pairs in the quantity contrasts, it is not completely clear if these contrasts were also reduced (or exaggerated) at faster speech rates. In Hungarian, to the authors knowledge, there is no systematic analysis of the spectral changes characterizing the production of the vowel quantity contrast in fast speech compared to comfortable speech. However, we have some indirect evidence of speech rate effects. A recent study analyzing infant directed speech, which was shown to be a generally slower speech style, showed that long vowels tended to be slightly longer in infant directed than in adult directed speech. This resulted in greater durational differences, that is, in contrast exaggeration between the long and short vowel pairs in infant directed speech. However, the spectral distinction of the quantity pairs did not differ in motherese and in adult directed speech, indicating no exaggeration of the contrast in the spectral domain [12]. These results suggest that duration serves as a more important cue for the vowel quantity contrast in Hungarian than spectral cues, which may thus be considered secondary.

In the present study, we hypothesized that increased speech rate induces reduction of the vowel length contrast in Hungarian and German. Our aim was to explore whether this reduction


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manifests differently in these two typologically unrelated languages, where the phonological vowel length contrast is expressed using similar means, using temporal and spectral cues, but in a different implementation. Specifically, we addressed the question if German and Hungarian differ in how they "prioritize" temporal and spectral cues in the vowel quantity contrast, and if they show differences to what extent they reduce or maintain the contrast in the temporal and the spectral domains.

## 2. Methods

We analysed short and long vowel pairs in monosyllabic words in the production of 15 Hungarian and 14 German speaking females.

In the Hungarian material, target vowels consisted of /u uː i iː ɒ aː/. In German, we used the corresponding /ʊ uː/, /ɪ iː/, and /a aː/ vowel pairs. (We refer to these pairs, as /u/-pairs, /i/-pairs, and /a/-pairs in the analysis, and the variable with these 3 levels is termed VOWEL TYPE.) Consonants preceding and following target vowels were controlled for place of articulation; they were either alveolar, laryngeal, or bilabial consonants (e.g., in German: *nass* [n**a**s] 'wet' vs. *Bahn* [b**a**ːn] 'train'; in Hungarian: *zár* [z**a**ːr] 'lock' vs. *tar* [t**ɒ**r] 'bald', where baldface denotes target vowels). Target words did not constitute minimal pairs, hence did not facilitate exaggeration of the vowel quantity contrast that could have blocked vowel (and contrast) reduction. Speakers produced target words in carrier sentences, where the target word bore sentence level accent in each case.

We recorded samples in two speech rate conditions: at i) comfortable/"normal" speech rate, and ii) maximum/"fast" speech rate. To achieve maximum speech rate, we used the method of [13]: we instructed speakers to repeat each target sentence several times starting at a comfortable tempo ("normal" speech) and increasing the speed with each repetition as much as possible. Each participant produced 6 of these sets for each target word resulting in 72 sets (144 analysed tokens) per speaker in total. We segmented all target words, and target vowels manually, and labelled the shortest words as the fast speech variants.

We analysed temporal and spectral measures in the two speech rate conditions using Praat [14]. In the temporal domain, we extracted and analysed raw target vowel durations to quantify speech rate effects on absolute vowel durations and we calculated and analysed duration ratio of short-long vowel pairs to quantify vowel quantity contrast in the temporal domain (averaged for each speaker, and for each vowel type). We opted to operationalize durational contrast as duration ratios of short to long vowels (and not duration differences of these vowels) on the basis of empirical evidence showing that it is the ratio between two durations rather than their absolute difference that controls human perceptual ability to discriminate them [15]. In the spectral domain, we extracted $F_1$ and $F_2$ frequency values in the middle 10% window of the vowel using the Burg algorithm (as a median of all estimated frequency values within that window). Then, we calculated and analysed the Euclidean distances of the quantity pairs in the $F_1 \times F_2$ vowel space (again, averaged for each speaker and each vowel type).

Data were submitted to linear mixed effects modelling separately for the two languages using lme4 [16] and lmerTest [17]) in R [18]. Pairwise comparisons were done using the emmeans package [19]), and in the case of duration ratios, we also used one sample t-tests to check if data was different from a predefined mean.

## 3. Results

On average, in fast speech, speakers produced words in half the length of that found in normal speech in both languages (normal $speech_{Hungarian}$ = 396.76±81.42 ms; fast $speech_{Hungarian}$ = 199.07±41.45 ms; normal $speech_{German}$ = 399.42±85.23 ms; fast $speech_{German}$ = 196.79±37.37 ms). We also found less variability in fast speech which reflects that speech production at higher speech rates is more demanding for speakers and puts stronger constraints on segment production.

In what follows, we present data separately for duration (Figure 1, 2, 3, and 4) and spectral measures (Figure 5, 6, 7, and 8) and we make comparisons between tendencies found in the two languages.

### 3.1. Duration

#### *3.1.1. Raw duration of vowels*

In general, Hungarian vowels were longer (normal speech: $dur_{short}$ = 119.43±44.97 ms $dur_{long}$ = 203.97±55.46 ms; fast speech: $dur_{short}$ = 68.54±24.62 ms; $dur_{long}$ = 94.63±28.53 ms) than German vowels (normal speech: $dur_{short}$ = 106.55±28.48 ms, $dur_{long}$ = 167.15±47.56 ms; fast speech: $dur_{short}$ = 62.15±21.19 ms; $dur_{long}$ = 73.59±28.99 ms). We also found that, as expected, long vowels were overall longer than short vowels in both languages.

Figure 1 and 2 shows vowel durations as a function of VOWEL QUANTITY, VOWEL TYPE, and SPEECH RATE in Hungarian and German. In both languages, these three factors had a significant interaction effect on the data [Hungarian: $F(2, 2095) = 16.5$; $p < .001$; German: $F(2, 1960) = 11.5$; $p < .001$]. This means that speech rate affected absolute vowel durations differently as a function of vowel type and vowel length.

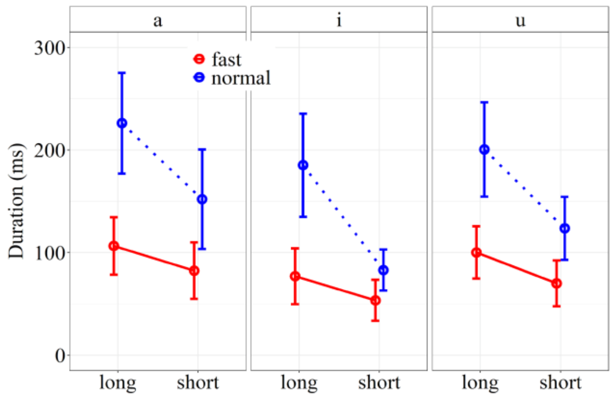


Figure 1: *Short and long vowels' duration (±95% confidence interval) in Hungarian as a function of vowel type and speech rate condition.*

According to the post hoc tests, temporal reduction in fast speech was significant in all vowels (irrespective of their quality and quantity) in both languages ($p < 0.05$). In spite of this, according to pairwise comparisons, members of all the vowel quantity pairs differed in both speech rate conditions in Hungarian. In German, however, durational reduction observed in fast speech led to the disappearance of the durational contrast between the quantity pairs /ʊ/-/uː/ and /ɪ/-/iː/ in fast speech: while all vowel pairs differed in duration in normal speech, in fast speech only /a/-/aː/ showed significant differences.

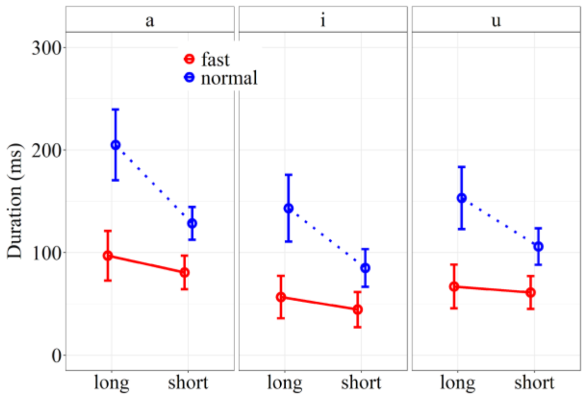


Figure 2: *Short and long vowels' duration (±95% confidence interval) in German as a function of vowel type and speech rate condition.*

### *3.1.2. Duration ratio of vowel quantity pairs*

Although we checked if vowel quantity pairs differed in their absolute durations in the post hoc analysis of the raw duration data above, our main measure to quantify the length contrast in the temporal domain was the duration ratio of short and long vowels; we present these data on Figures 3, and 4. In these figures, dashed lines positioned at 1 denote the situation where short and long vowels' duration is equal, that is, vowel quantity contrast may be considered completely neutralized in the temporal domain. These data show slightly different results from those of raw durations with respect to the realization of the quantity contrast, and ratio data reflect more directly the perceptual representation of the contrast in the temporal domain [15].

In general, duration ratio of short to long vowels was greater in Hungarian than in German in normal speech (Hungarian 1.80±0.51, German = 1.58±0.25), and in fast speech (Hungarian = 1.40±0.20; German = 1.20±0.19) as well. Linear mixed effects modelling of short-long ratio data showed significant VOWEL TYPE × SPEECH RATE interaction effects for Hungarian [$F(2, 75) = 16.9$; $p < .001$], and significant SPEECH RATE [$F(1, 14) = 61.4$; $p < .001$] and VOWEL TYPE [$F(2, 19) = 22.9$; $p < .001$] main effects for German. This means that while in Hungarian, speech rate affected temporal distinction of vowel quantity pairs differently as a function of vowel type, in German, we found that speech rate affected all vowel pairs equally. Let us now take a look at these data in detail.

In Hungarian, we found that in normal speech, the /i/-/iː/ contrast was the greatest of all contrasts (as expressed in duration ratios), while the /u/-/uː/ and /ɒ/-/aː/ pairs were both less clearly distinguished in duration. (According to the post hoc tests, duration ratios of /u/ to /uː/ and /ɒ/ to /aː/ did not differ significantly.) This is surprising given that it is generally assumed that low vowel quantity pairs are distinguished more than high vowel quantity pairs using durational cues (in part, due to biomechanic reasons). And to this assumption previous empirical studies also provided some evidence showing that the low /ɒ/ and /aː/ were differentiated the most by Hungarian adult speakers in adult directed speech produced at a comfortable speech rate (as captured in duration ratio of short and long vowels), while high vowel pairs were differentiated less extensively by the same speakers [12]. Unexpected results in the present study seem to originate in the fact that short /i/s at normal speech rate were realized in extremely short durations in this data set. Nevertheless, ratio of all vowel quantity pairs was above 1, that is, vowels were distinguished durationally at normal speech rate.

Similarly to Hungarian, the ratio of the high front pair, that is, /ɪ/ to /iː/ was the greatest in normal speech in German and this was significantly greater than the ratio of /ʊ/ to /uː/ ($p < 0.01$). The ratio of /a/ to /aː/ was positioned between the other two. Consistent with the tendencies observed in Hungarian, the ratio of short to long vowels was above 1 for all vowel types in German at the normal speech rate.

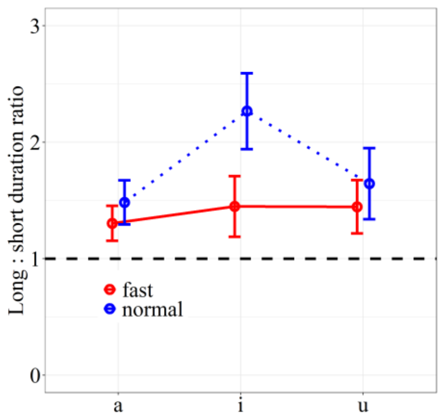


Figure 3: *Long and short vowels' duration ratio (±95% confidence interval) in Hungarian as a function of vowel type and speech rate condition (the dashed black line represents the case of complete neutralization).*

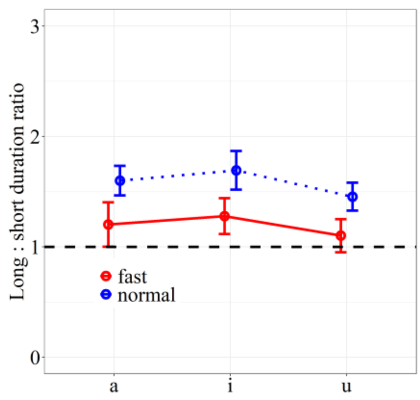


Figure 4: *Long and short vowels' duration ratio (±95% confidence interval) in German as a function of vowel type and speech rate condition (the dashed black line represents the case of complete neutralization).*

Pair-wise comparisons revealed that in fast speech, only /i/ to /iː/ duration ratios decreased significantly (which was the largest ratio in normal speech) in Hungarian. As a result of temporal reduction, distinction of all vowels pairs became similar to one another (irrespective of their vocalic quality). However, values in fast speech were still observed to be positioned above 1, that is, duration ratios did not reflect neutralization of the quantity contrast in Hungarian in any of the tested quantity pairs.

In German, all vowel pairs showed significant decrease in their duration ratios in fast speech, but the differences we found in normal speech between the three quantity pairs were preserved. This means that in fast speech, /ɪ/ and /iː/ were still distinguished the most in their duration, compared to /ʊ/ vs. /uː/, and /a/ vs. /aː/. Reduction of the /ʊ/-/uː/ contrast in fast speech resulted in the /ʊ/ to /uː/ ratios approximating 1. That is, the temporal distinction of /ʊ/ and /u/ reduced in a manner that the contrast seemed to reach the case of complete neutralization, while the /a/-/aː/, and /ɪ/-/iː/ contrasts were maintained more clearly in the temporal domain in fast speech. However, according to a one-sample t-test, duration ratios of /ʊ/ to /uː/ were different from 1 which suggests that complete neutralization was not reached, at least, not from the aspect of speech production.

### 3.2. Spectral realization

We now move on to the spectral realization of vowels. Figures 5 and 6 show first and second formant frequencies estimated in vowels in normal (left side) and fast (right side) speech rate conditions. To get a general impression of speech rate effects, we first displayed vowels in the $F_1 \times F_2$ vowel space in the two conditions, where spectral reduction (centralization) of vowels may be readily observed.

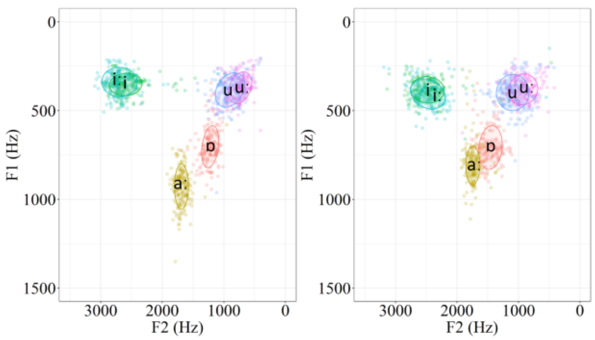


Figure 5: *Vowel realizations in normal (left) and fast (right) speech in Hungarian in the $F_1 \times F_2$ vowel space.*

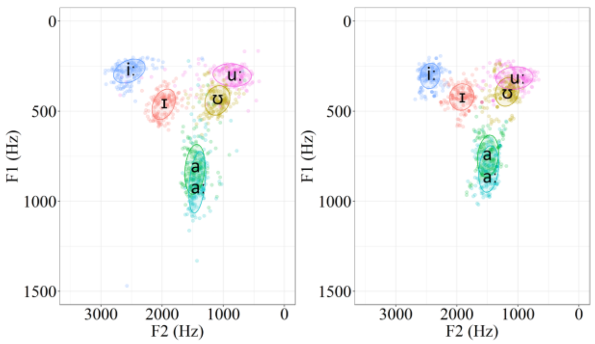


Figure 6: *Vowel realizations in normal (left) and fast (right) speech in German in the $F_1 \times F_2$ vowel space.*

As expected, vowels were produced more centralized in fast speech in both languages (Figures 5, 6). However, the magnitude of the quality shift of vowels varied depending on the vowel type and the language in question. We delve deeper into this by analyzing the Euclidean distances of the vowel quantity pairs in the $F_1 \times F_2$ vowel space.

In Hungarian, Euclidean distances of short-long vowel pairs (Figure 7) showed significant interaction effect of VOWEL TYPE and SPEECH RATE [$F(1, 75) = 11.24$, $p < .01$], meaning that speech rate affected vowels differently as a function of the given vowel contrast. In German, we found significant main effects of SPEECH RATE [$F(1, 70) = 5.3$; $p < .05$] and VOWEL TYPE [$F(2, 70) = 193.0$; $p < .001$], which implicates that vowel contrasts were reduced equally in the spectral domain.

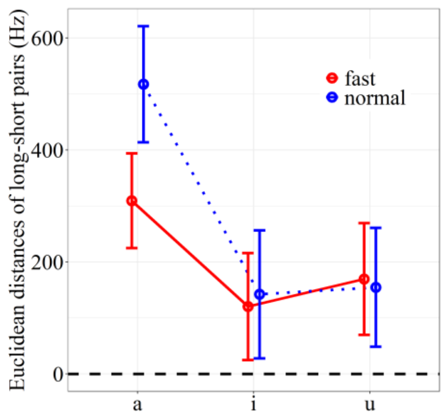


Figure 7: *Euclidean distances (±95% confidence interval) of short and long vowels in the $F_1 \times F_2$ vowel space Hungarian as a function of vowel type and speech rate condition (the dashed black line represents the case of complete neutralization).*

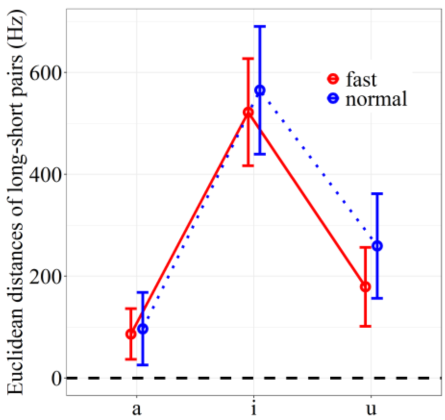


Figure 8: *Euclidean distances (±95% confidence interval) of short and long vowels in the $F_1 \times F_2$ vowel space in German as a function of vowel type and speech rate condition (the dashed black line represents the case of complete neutralization).*

Post hoc analyses revealed that, in line with expectations, /a/-contrasts were greater than /u/-contrasts and /i/-contrasts spectrally in Hungarian, while /u/-contrasts and /i/-contrasts did not differ significantly from each other. This pattern was observed in both speech rate conditions (Figure 7), but we also found that the /ɒ/-/aː/ contrast reduced in fast speech significantly ($p < 0.05$), while /u/-/uː/ contrast and the /i/-/iː/contrast did not change in the spectral domain due to the increased speech rate.

In German, in line with expectations, /ɪ/ vs. /iː/ contrasts were the largest spectrally, followed by /ʊ/ vs. /uː/ and /a/ vs. /aː/ in both speech rate conditions (Figure 8). Pairwise differences between all three pairs were significant (at $p < 0.05$), as shown by post-hoc tests. In fast speech, none of these contrasts reduced significantly, that is, spectral distinction of all vowel quantity pairs was maintained equally in both speech rate conditions in German.

## 4. Discussion and Conclusions

In the present study, we aimed to investigate whether increased speech rate induces reduction of the vowel quantity contrast in Hungarian and German. Further, we also explored if reduction manifests differently in these two typologically unrelated languages, where the phonological vowel length contrast is expressed using similar means, namely temporal and spectral cues, but in a different implementation. Specifically, we addressed the question if German and Hungarian differ in how they "prioritize" temporal and spectral cues in the vowel quantity contrast, and if they show differences to what extent they reduce or maintain the contrast in the temporal and the spectral domains. For the purposes of the study, we facilitated production of vowels at comfortable speech rates ("normal" speech), and at maximal speech rates ("fast" speech) and analyzed normal and fast speech realizations of the vowels and the quantity contrast using temporal and spectral measures.

We found that at comfortable tempo, German and Hungarian long and short vowel pairs were extensively distinguished by quality and duration. In fast speech, all vowels reduced in duration compared to normal speech rates, but the quantity contrast (as expressed in duration ratio of short to long vowels) did not reduce equally in the two languages. More specifically, in Hungarian we found that only the /i/-/iː/ contrast was reduced in duration, but in spite of this, all vowel quantity pairs were differentiated clearly in fast speech, similar to normal speech. In German, all contrasts reduced in the temporal domain, but only the /ʊ/-/uː/ pairs seemed to approximate the case of complete neutralization. On this basis, we can first conclude that vocalic quantity contrasts were maintained in both speech rate conditions in both languages in the temporal domain, but we found more reduction in German at fast speech rates than in Hungarian. Second, on the basis of the above we can also conclude that temporal cues may be considered robust correlates of the vowel quantity contrast in production, irrespective of the fact that vowel quality may also cue the quantity contrast in addition to duration.

With respect to spectral measures, vowel quantity pairs were distinguished at normal speech rates (as expressed in Euclidean differences of vowels in the $F_1 \times F_2$ vowel space), as expected: in Hungarian, /ɒ/ and /aː/ were differentiated the most among the tested vowel pairs, while in German, /ɪ/ and /iː/ showed the greatest distinction. In fast speech, we found spectral reduction of the /ɒ/-/aː/ contrast in Hungarian (but /ɒ/-/aː/ was still differentiated the most using spectral means in fast speech among all vowels), and no reduction in any of the tested pairs was observed in German. This means that the vowel quantity contrast was maintained in production similarly across speech rates using spectral cues in both languages, implying that vocalic quality is also a strong and robust correlate of the vowel quantity contrast in both languages.

It is important to note that in the present study, we did not test whether the temporal and spectral means that distinguished the vowel quantity pairs in production may also serve as acoustic cues for the human auditory perception of the given contrast. This question should be addressed in future research. Nevertheless, the present results suggest that temporal and spectral cues are equally important for expressing vowel quantity contrasts in production in both German and Hungarian, since speakers clearly made efforts to preserve these signals in the speech stream, even in fast speech, that is, under increased production constraints. This conclusion challenges the notion of acoustic cues being 'primary' and 'secondary', with secondary cues being potentially redundant, as we did not find any of these cues to be more easily sacrificed under higher constraints on speech production.


## 5. Acknowledgements

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