SPEECH RATE AND VOWEL QUALITY EFFECTS ON VOWEL-RELATED WORD-INITIAL IRREGULAR PHONATION IN HUNGARIAN

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Abstract
We examined utterance-initial irregular phonation as a function of vowel quality (vowel height and backness), and speech rate in Hungarian. In the analysis we distinguished two types of irregular phonation: glottalization and glottal stop. In Experiment 1, all nine Hungarian vowel qualities were analysed in pseudo words, with respect to the extent they facilitate the occurrence of irregular phonation as a function of their (i) vowel height (three levels: close, mid, open), (ii) backness using two levels in the first run (front vs. back) and three levels in the second run (front vs. central vs. back), and (iii) speech rate. In Experiment 2, four vowel qualities were analysed in real Hungarian words with respect to all the above factors (but in this analysis, only two categories were distinguished in the backness dimension). With respect to vowel height, we found that open vowels elicited more irregular phonation than mid and close vowels in both experiments. With respect to backness, in the twofold comparison (front vs. back) we found no effect in either of the experiments, while in the threefold comparison (front vs. central vs. back) we found that back vowels showed a higher ratio of irregular phonation than central and front ones in Experiment 1. The frequency of occurrence of irregular phonation was higher in fast than in slow speech in Experiment 1, and it was lower in Experiment 2 (in the latter, the confounding effect of the hiatus position was eliminated which was probably present in Experiment 1). The relative frequency of glottalization did not show an increase as a function of increased speech rate as claimed by earlier studies.

Keywords: irregular phonation, glottal stop, glottalization, vowel quality, speech rate

DOI: http://doi.org/10.18135/CAPSS.49

1 Introduction

In the present study we analyse irregular phonation in utterance-initial vowels, and we address the questions if and how the quality of the vowel and the speech rate affect its frequency of occurrence. For some aspects of these questions evidence has already been gathered in several languages, but a systematic analysis of the factors of vowel quality and the speech rate (and their interaction) has not been carried out so far. Moreover, in most cases the effect of speech rate was evaluated in a not very strictly controlled experimental design, which also raises questions with respect to the generality of conclusions drawn from these previous results. Our main questions are if vowels may elicit the occurrence of irregular phonation to a different extent as a function of their quality (with special attention paid to their height and backness features), and if speech rate affects the frequency of occurrence of irregular phonation if it is analysed in laboratory speech where the increase of speech rate is elicited in a well-controlled fashion. In addition to the frequency of occurrence of vowels realized with irregular phonation, patterns of frequency of occurrence of glottalization and glottal stops in terms of vowel quality and speech rate were also analysed to reveal the interrelations of speech rate and the type of irregular phonation the vowels are realized with.

1.1 Irregular phonation

Modal voice is defined in the literature as quasi-periodic vibration of the glottal folds (e.g., Gósy, 2004), and is considered to be the most common type of phonation. However, in some cases, voice production may depart from this typical pattern, and phonation may become irregular. Irregular phonation is used as an umbrella term in the literature, covering several types of irregularity in vocal fold vibration. Besides *irregular phonation,* other terms like *laryngealization, glottalization, creaky voice,* etc. are also used, and in several cases they refer to only more or less similar realizations of irregularity in the voice source. Based on their formal characteristics, some authors use more accurate definitions for the subtypes of irregular phonation, (e.g., Batliner et al., 1993; Dilley et al., 1996), while in several studies the concept of irregularity is introduced in a more intuitive manner. Considering the terminological variability, it is crucial that we clarify our use of terms in the present work. We refer to irregularity in the voice source in general using the term *irregular phonation.* In the present study, we investigate two easily distinguishable types of irregular phonation. For one of these phenomena we apply the term *glottalization* (covering several possible subtypes) to refer to cases where irregularity can be observed as consecutive periods in voicing differing evidently in terms of duration, amplitude, or both. The second phenomenon is a single glottal gesture which we refer to as *glottal stop* (Figure 1).

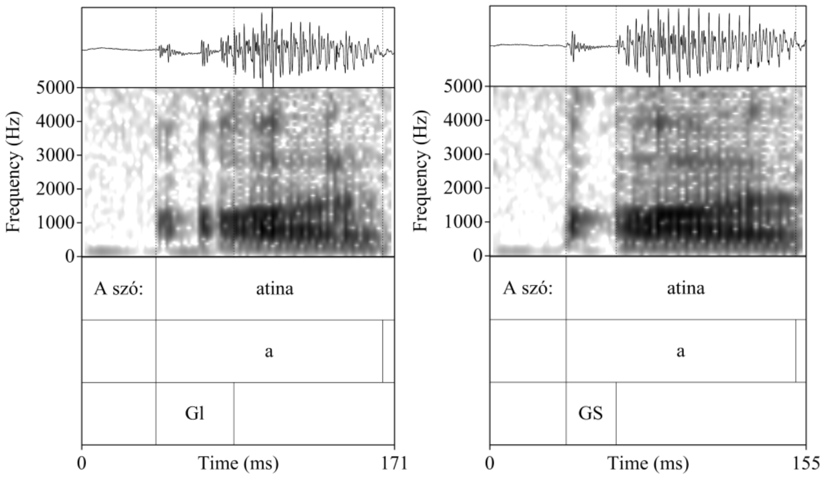

Figure 1.
Examples of glottalization (left) and glottal stop (right)

Irregular phonation serves prosodic functions in a number of typologically unrelated languages, e.g., American English (Dilley et al., 1996), Czech, Spanish (Bissiri et al., 2011), German, Polish (Kohler, 2001; Malisz et al., 2013), Hungarian (Markó, 2013) and others. The occurrence of irregularity in the voice source may be influenced by several factors (see some of these below), and it shows high inter- and intraspeaker variability (e.g., Dilley et al., 1996; Redi & Shattuck-Hufnagel, 2001). It was also shown that the less speakers glottalize, the more probable it is that they do so in a phrase-, word- or vowel-to-vowel boundary (hiatus) position (Markó, 2013).

A number of studies have found irregular phonation to predominate among male speakers in several speech communities (e.g., Stuart-Smith (1999) in Glasgow; Esling (1978) in Edinburgh; Henton and Bladon (1988) for speakers of RP and ‘Modified Northern’ English). Nevertheless, despite strong associations between irregular phonation and the male gender, the opposite tendency is also documented in the literature. For example, irregular phonation was found to be prevalent in college-aged women in Virginia (Lefkowitz, 2007, cited by Podesva, 2013), and young Californian women also use it significantly more often than their male counterparts (Yuasa, 2010). Podesva (2013) found similar tendencies independently of age and race in the Washington, DC, Metropolitan Area. In Hungarian, irregular phonation was found to be more frequent in young and middle-aged females’ speech than in male speakers of the same age groups (see Markó, 2013).

Kohler (2001, pp. 282–285) defined four types of irregular phonation (which he generally labelled as *glottalization* covering “the glottal stop and any deviation from canonical modal voice") as follows. (1) Vowel-related glottalization phenomena which signal the boundaries of words or morphemes. (2) Plosive-related glottalization phenomena which occur as reinforcement or even replacement of plosives. (3) Syllable-related glottalization phenomena which characterize syllable types along a scale from a glottal stop to glottalization (e.g., Danish stød). (4) Utterance-related glottalization phenomena which comprise (i) phrase-final relaxation of phonation, and (ii) truncation glottalization, i.e., utterance-internal tensing of phonation at utterance breaks.

Initial irregular phonation in vowels (a specific case of type (1) above) was analyzed in several studies. Malisz et al. (2013) examined the conditioning effect of speech style (speech vs. dialogue), presence of prominence, phrasal position (initial vs. medial), speech rate, word type, preceding segment, and following vowel height on the frequency of occurrence of word-initial (and vowel-related) glottalization in Polish and German. They concluded – among other points – that vowels bearing prominence were more frequently marked glottally (in both languages); faster rates reduced glottal marking in general, but especially the number of glottal stops; and that faster rates increased the relative frequency of the occurrence of glottalization. They also found that low vowels were more frequently glottalized in both languages than non-low vowels; however, it must also be noted that the factors of speech rate and vowel quality were not systematically varied in this study.

Lancia and Grawunder (2014) used pseudo-words to facilitate initial irregular phonation in vowels, and to analyze the conditioning factors of vowel height (high vs. low: /i/ vs. /a/), the presence of stress, and the place of articulation of the preceding consonants. They concluded that retracted tongue (i.e., low/back tongue position) favors the production of irregular phonation (particularly strongly in unstressed syllables).

In Hungarian a systematic analysis of the effect of speech rate and vowel quality in initial irregular phonation in vowels has not been carried out so far; in addition, to the authors' knowledge, a study considering the interaction of these factors, or the separate analysis of the effect of such vowel features as vowel height and backness is also nonexistent for any other languages either. Moreover, in earlier studies investigating vowel-related voice source irregularity in Hungarian (e.g., Markó, 2013), glottalization and glottal stops were not treated as separate categories; as a result, no data is available on the relative frequency of these two types either.

1.2 Speech rate

There are a number of measures that are used to parameterize speech rate in timing studies from average syllable duration (ASD) to words/minute (see an overview in Fletcher, 2010). If we want to compare tempo characteristics of segmentally identical sentences, it is also a possibility to simply compare total sentence durations (see e.g., Smith, 2010).

Global and local speech rate measures can be differentiated; however, the use of these terms is rather confusing in the literature. In the present study we refer to speech rate as a global characteristics of the utterance, where micro-temporal variation (like, e.g., phrase-final lengthening) is not considered in more detail.

1.3 The Hungarian vowel inventory

The Hungarian vowel inventory includes 14 vowels (see Figure 2), which are paired in the dimension of quantity resulting in 7 short-long phonological pairs. However, the members of two short-long pairs (/ɛ/ and /eː/; /ɒ/ and /aː/) differ in their phonetic characteristics as well; therefore, from a phonetic point of view, 9 vowel qualities can be differentiated in Hungarian.

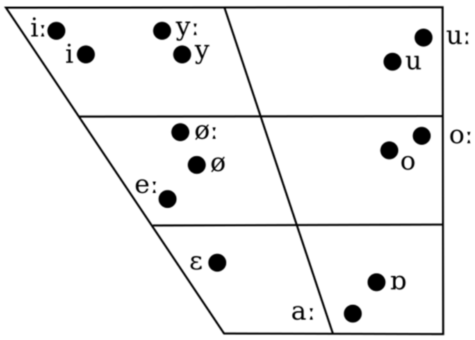

Figure 2.
The Hungarian vowel inventory (after Szende, 1994: 92)[1]

According to the traditional view in Hungarian phonetics (see, e.g., the textbooks of Kassai, 1998; Gósy, 2004), vowels are differentiated on the vowel height dimension as follows: /i y u/ are considered as close vowels, /eː ø o/ are categorized as close-mid, /ɛ/ is considered as open-mid, and /aː/ is considered as an open vowel. The short phonological counterpart of /aː/ in this view is considered to be the open-mid /ɔ/, while others (e.g., Mády, 2008) define the vowel at hand as an open /ɒ/. (Note that in the present paper, we adhere to the latter notation and analysis.)

[1]SVG version of IPA vowel chart for Hungarian, showing the "short a" as a rounded vowel in contrast to Szende (1994).
https://commons.wikimedia.org/wiki/File:Hungarian_vowel_chart_with_rounded_short_a.svg

According to the traditional view again, with respect to backness, /i y eː ø ɛ/ are considered as front vowels, while /u o ɒ aː/ are characterized as back vowels. It should also be noted, however, that the status of the vowel /aː/ is ambiguous: while it is uniformly transcribed with the IPA symbol of a front vowel, it is generally classified as a back vowel (based on its morpho-phonological behavior, namely its participation in the Hungarian vowel harmony) both by the phonological (e.g., Siptár & Törkenczy, 2007) and the phonetic literature.

Although the characteristics of the vowel system on the height dimension are more or less generally agreed on, with respect to the backness distinction there is another competing view on the vowel system which was introduced by Bolla (1995). On the basis of the articulatory (X-ray) analysis of Hungarian vowels, Bolla (1995) claimed that /i eː ɛ/ are front vowels, /y ø aː/ are central vowels, while /u o ɒ/ are back vowels.

Since the present study focuses on the question if vowels may elicit the occurrence of irregular phonation to a different extent as a function of their quality with special attention paid to their backness and vowel height features, we will introduce both the twofold and the threefold analysis of the backness feature in the analysis of our data, where applicable, to get a deeper insight into the question at hand (see Experiment 1, and sections 2.2.2 and 2.2.3). Additionally, through the application of the threefold opposition, we also hope to resolve the bias inherent in the twofold analysis due to the ambiguous status of /aː/ (namely, that it is a central vowel but categorized as a back vowel due to its phonological behaviour).

1.4 Aims and hypotheses

In the present study we investigated the effect of vowel height and backness and speech rate in two experiments, using phonetically balanced speech materials, which were also carefully controlled with respect to speech rate. In the analysis, two types of irregular phonation were taken into account: glottalization and glottal stop. In Experiment 1 we recorded pseudo-words in order to analyse all of the 9 different vowel qualities of Hungarian (irrespective of quantity, i.e., /i y u eː ø o ɛ ɒ aː/, see Figure 2) in the same context. In Experiment 2, we used the same design with real words, and analysed 4 vowel qualities /i o ɛ ɒ/.

Based on previous results for other languages, we addressed the following questions. Is irregular phonation more frequent in word-initial vowels in Hungarian if (i) the speech rate is slow (as opposed to fast); (ii) the vowel is back (as opposed to front); (iii) the vowel is open (as opposed to close or close-mid)? (iv) Do glottal stops occur less frequently in fast speech, while the relative amount of glottalization increases?

We hypothesized that the frequency of occurrence of irregular phonation in general is higher in slow speech than in fast speech. Furthermore, we assumed that back vowels elicit irregular phonation in a higher ratio than front ones both in slow and fast speech, and that open vowels favour irregular phonation more than non-open (close or close-mid) ones due to tongue retraction associated with the back and open articulatory positions. Finally, we also assumed that faster speech rate reduces the number of glottal stops, but increases the relative frequency of glottalization.

2 Experiment 1

2.1 Material and method

2.1.1 Material

The test material consisted of trisyllabic pseudo-words which fit into the phonotactic patterns of the Hungarian language. Each of the different Hungarian vowel qualities (/i y u eː ø o ɛ ɒ aː/, see Figure 2) appeared as the first syllable of the construction V*tina,* where both word-stress (given that word stress is fixed on the first syllable in Hungarian) and pitch accent were expected in all cases. These nonsense target words were embedded in the following phrase: *A szó:* [target word] 'The word is: [target word]'.

2.1.2 Experimental design

The stimuli were presented to the speakers on a computer screen. Each trial consisted of two display screens: first the introductory part *(A szó:)* was shown to the participant, then the target word was displayed (see Figure 3). The participants' task was to read aloud the target word, but not the introductory part.

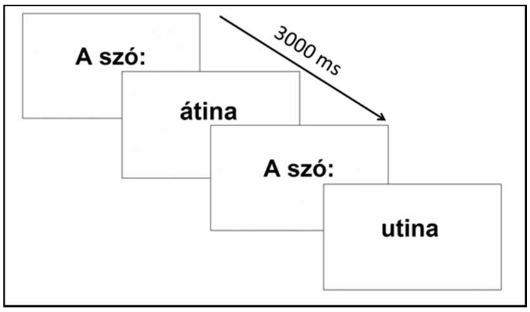

Figure 3.
Two consecutive trials with the four corresponding display screens timed 1500 ms each (resulting in 3000 ms for one trial)

In order to elicit speech rate differences between the conditions, the timing of the display screens was manipulated. In the "slow" speech condition, each display screen appeared for 1500 ms resulting in 3000 ms for one trial in total (including the introductory part and the target word). In the "fast" speech condition the timer was set to 300 ms, resulting in 600 ms for one trial in total.

(During the recordings several other timer settings were also applied, and the setting to serve as the "fast" condition was selected posterior to the recordings on the basis of the speakers' ability to produce the items properly, i.e., separately and without errors.) As the timing of the introductory part reflected also the timing of the target word, it enabled the speakers to prepare for the production of the latter.

The trials were ordered into blocks: within each block all nine different target words occurred in a randomized order once, and these blocks were repeated 5 times consecutively for each ("slow" and "fast") condition. First the "slow" condition, then the "fast" condition was recorded in the case of every participant. 9 vowel qualities/target words × 5 repetitions × 2 speech rate conditions, i.e., 90 vowels per speaker were recorded. The recordings were made in a sound-treated booth, using a tie-clip omnidirectional condenser microphone and an external soundcard.

2.1.3 Participants

As previous results revealed that Hungarian female speakers tend to produce irregular phonation more frequently than male speakers (see e.g., Markó, 2013); in the present study only female speakers were included. All 14 of them were university students, and native speakers of Hungarian, who reported no hearing or speech deficits. In order to ensure that the "slow" and the "fast" conditions differentiate properly (i.e., they may be differentiated by a conceptually sound value), a threshold for the speech rate difference was introduced (see below, in 2.1.5).

This threshold was not exceeded by the data in the case of 4 participants, thus finally in the main analysis 10 speakers' material was involved. The speakers' age ranged between 23 and 28 years, with a mean of 25 years.

2.1.4 Annotation

The target word, the word-initial vowel, and the irregular phonation at the beginning of the word-initial vowel were labelled manually in Praat (Boersma & Weenink, 2016).

The vowel qualities were identified automatically (on the basis of the stimulus order), and then checked by the annotators (two of the authors of the present paper) auditorily. In the case of mispronunciation or any other errors involving the production of the vowel of interest, the vowel was excluded from the material. Vowel boundaries were defined on the basis of the F_2 trajectory.

The labeling of the irregular phonation was performed in accordance with the methodology proposed by previous studies (e.g., Dilley et al., 1996; Bőhm & Ujváry, 2008) in which visual (waveform and spectrogram) and auditive information was combined. A given vowel was labelled as irregularly phonated if (i) its first consecutive periods differed evidently in terms of duration, amplitude, or both (these cases were marked as glottalization, Figure 1, left), or if (ii) one (or more) glottal stop(s) was/were observed at the beginning of the vowel (these cases were marked as glottal stop, Figure 1, right).

We analysed the ratio of vowels produced with irregular phonation with respect to vowel quality, vowel height and backness, and speech rate. We also determined the ratio of glottalized vowel occurrences to the total number of vowels realized with irregular phonation, and compared that to the ratio of vowels realized with glottal stops in the two speech rate conditions.

2.1.5 Control of speech rate

Given that one of the aims of the present study was to compare "slow" and "fast" speech with respect to the frequency of occurrence of initial irregular phonation in vowels, it was inevitable to properly control for the difference of speech rate between these two conditions. To achieve this goal, first we manipulated the timing of the display screens (see above); however, according to the authors' perceptual judgement, this did not necessarily lead to considerable differences between the speech rates of the two analysed conditions speakerwise. Therefore, we decided to set a perceptually motivated threshold for the speech rate differences.

In the case of Hungarian, the just noticeable difference (JND) for speech tempo has not been studied so far; however, there are JND data for other languages which may be taken as a reasonable reference for Hungarian as well. For instance, for Dutch speech fragments Quené (2007) found 5% JND for artificially increased/decreased speech rate differences, while he also noted that this value may be an overestimation and that in the case of everyday communicative situations, the JND is probably lower.

As in our case the number of the phonemes per item was constant, to calculate speech rate differences, not the speech sound per duration values, but only the word durations were measured and compared in the two speech rate conditions. The five repetitions of each word were analysed and averaged for this comparison. The mean durations (± one SD) in "slow" and "fast" conditions for those 10 speakers who differentiated their speech rates by more than 5% on average can be seen in Figure 4. The duration difference between the two conditions ranged between 5% and 20% speakerwise, and the mean of the differences was 11±5.3%. The average item duration was 535±54 ms in the "slow" condition, and 483±52 ms in the "fast" condition (for all of the 10 speakers pooled).

2.1.6 Statistical analyses

Three 2-way repeated measures ANOVAs were performed with the factors (i) *vowel quality* and *speech rate,* (ii) *vowel height, backness,* and *speech rate,* and (iii) *vowel height, backness,* and *speech rate,* but in the latter case the feature backness was redefined to contain three levels instead of two, on the basis of the analysis of Bolla (1995) (see 1.2 and 2.2.3 for further details). The confidence level was set to 95% in each case.

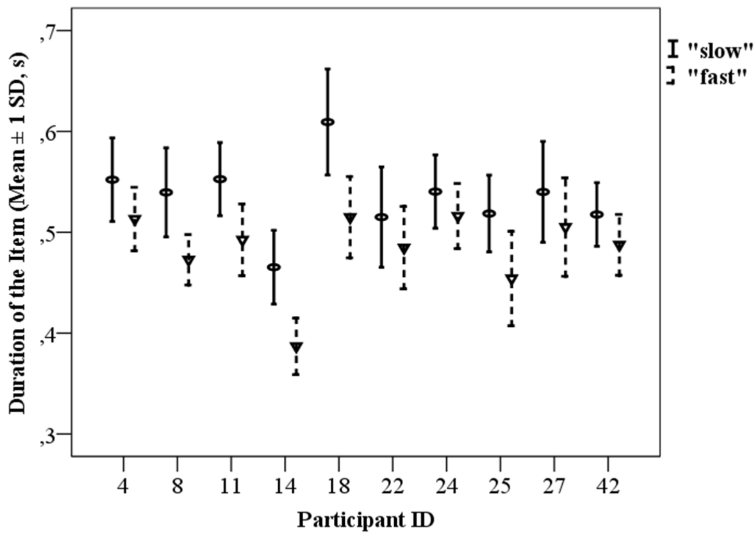

Figure 4.
The duration of items as a function of speech rate condition, speakerwise (mean ± SD)

2.2 Results

2.2.1 Vowel-initial irregular phonation as a function of vowel quality and speech rate

The ratio of vowels produced with irregular phonation (pooled over speakers) as a function of *vowel quality* and *speech rate* is presented in Figure 5.

In the "slow" condition the ratio of initial irregular phonation in vowels was 74.0±16.9% on average, while in the "fast" condition 79.5±7.2%. A repeated measures factorial ANOVA showed significant interaction of the vowel quality and the speech rate factors $F(8, 72) = 2.84$, $p = 0.008$, revealing that increased speech rate affects the frequency of occurrence of irregular phonation in the vowels differently. These differences will be further explored in the analysis by vowel features below.

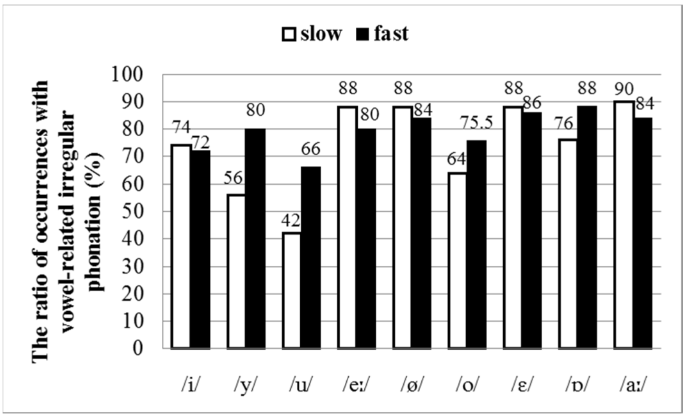

Figure 5.
The ratio of vowels produced with any kind of irregular phonation
as a function of vowel quality and speech rate

2.2.2 Initial irregular phonation as a function of vowel height, backness (two levels), and speech rate

In the present analysis, on the vowel height dimension /i y u/ were considered as close vowels, /eː ø o/ were considered as mid vowels, and /ɛ ɒ aː/ were considered as open vowels. Note that this is a simplification of the traditional view of Hungarian phonetics (see 1.2), but we argue that it is highly tenable on the basis of the figure of Szende (1994), which represents the Hungarian vowel inventory (see Figure 2). Additionally, this simplification also balances the conditions numerically on a scientifically sound basis, which thus corrects the bias introduced by the imbalance of the four-level analysis.

In the first model, again on the basis of the traditional phonetic and phonological classification of Hungarian vowels, we considered /i y eː ø ɛ/ as front vowels, while /u o ɒ aː/ were characterized as back vowels (see e.g., Gósy, 2004; Siptár & Törkenczy, 2007).

The ratio of vowels produced with irregular phonation as a function of vowel height and speech rate is shown in Figure 6, while the ratio of vowels produced with irregular phonation as a function of backness (consisting of the two levels, back and front) and speech rate is shown in Figure 7.

With respect to the frequency of occurrence of initial irregular phonation in vowels, significant interaction effect of *vowel height* and *speech rate* was found ($F(2, 18) = 5.20$, $p < 0.05$), reflecting that speech rate affected vowels differently according to their height. The pairwise comparisons revealed that in the "slow" speech condition, the mid and the close vowels ($p = 0.002$), and the open and the close vowels ($p < 0.001$) differed significantly, while in the "fast" speech condition, the open and the close vowels ($p = 0.02$) were differentiated with respect to the frequency of irregular phonation. However, we found no effect of backness (Figure 7).

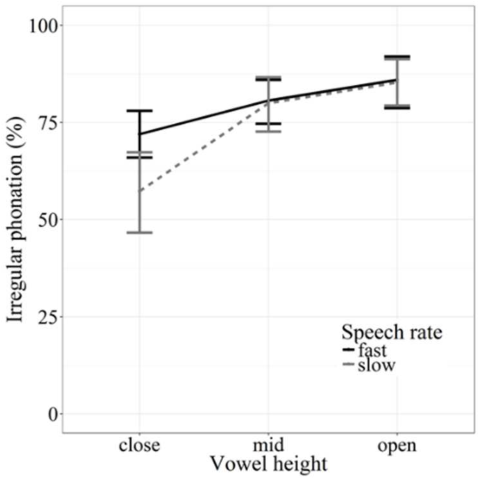

Figure 6.
The ratio of vowels produced with any kind of irregular phonation as a function of vowel height and speech rate (mean + 95% CI)

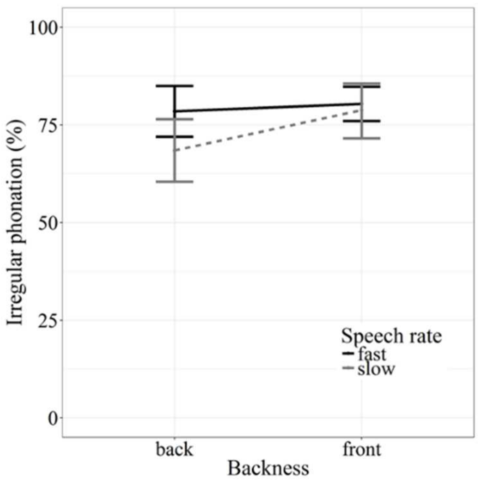

Figure 7.
The ratio of vowels produced with any kind of irregular phonation as a function of backness (two levels) and speech rate (mean + 95% CI)

2.2.3 Initial irregular phonation as a function of vowel height, backness (three levels) and speech rate

As mentioned above, another possible analysis of the backness feature in Hungarian vowels is to treat them in a threefold contrast, and differentiate back /u o ɒ/, central /y ø aː/, and front /i eː ɛ/ vowels (see Bolla, 1995, p. 211). Since in the present paper we do not intend to decide in favor of either of the possible analyses, but we acknowledge the more fine-grained nature of the latter one, we opted for testing this categorization as well, and see if this may reveal any trends that remained hidden in the model using the more traditional approach.

The ratio of vowels produced with irregular phonation as a function of backness (with three levels) and speech rate is shown in Figure 8. According to an ANOVA, the factors *vowel height, backness,* and *speech rate* display two interaction effects on the ratio of vowels realized with irregular phonation: *speech rate* interacts with *vowel height* ($F(2, 18) = 3.97$, $p < 0.05$), and *speech rate* interacts with *backness* ($F(2, 18) = 6.04$, $p < 0.01$), as well. Obviously, the interaction of *speech rate* with *vowel height* is the same effect we found while fitting the previous model. The interaction of *speech rate* and *backness* is, however, a new finding that emerged from the recategorization of the data. According to the pairwise comparisons, this interaction is due to the fact that there is a significant difference between the “slow” and “fast” conditions in the case of back vowels ($p < 0.05$), but we do not see this differentiation of the two tempo conditions in the central or in the front vowels. What is more, as opposed to the trend seen in back and central vowels, in the case of front vowels, the “slow” condition seems to have elicited more vowels with irregular phonation.

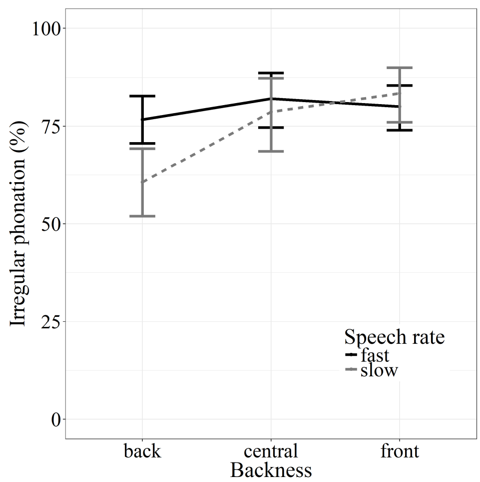

Figure 8.
The ratio of vowels produced with any kind of irregular phonation as a function of backness (three levels) and speech rate (mean + 95% CI)

2.2.4 Ratio of glottalization and glottal stops as a function of vowel quality and speech rate

Relative to the number of all irregular occurrences both in the "slow" and the "fast" conditions, the ratio of glottalization (55.9±9.2% and 66.3±9.2% of all irregular occurrences, respectively) exceeded the ratio of glottal stops (44.1±9.2% and 33.7±9.2% of all irregular occurrences, respectively) in general. The only exception we found was the vowel /u/, in which the ratio of glottal stops (66.7%) was well above the ratio of glottalization (33.3%) in the "slow" condition.

The ratio of glottalization in the "fast" condition exceeded that of the "slow" condition in all vowels but /y/. The ratio of glottalization and glottal stops were close to equal in the case of /y/ in both the "slow" (53.6 vs. 46.%) and the "fast" (52.5 vs. 47.5%) condition. The ratio of occurrences of glottal stops and glottalization as a function of vowel quality and speech rate are presented in Figure 9.

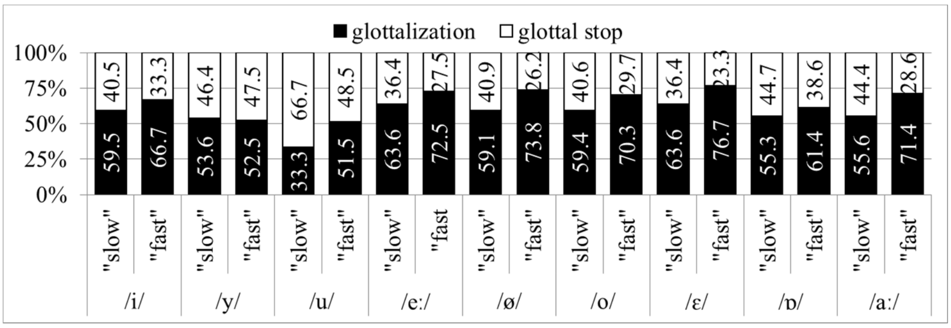

Figure 9.
The ratio of the two types of irregular phonation (relative to all irregular occurrences) as a function of vowel quality and speech rate

In the case of the close vowels, the ratio of glottalization was 51.1% in the "slow" condition and 56.9% in the "fast" condition, relative to the number of all irregular occurrences. This means that in the close vowels the ratio of glottalization and glottal stops were close to equal. The mid vowels showed the highest ratios of glottalization: 60.8% and 72.3% (in the "slow" and the "fast" conditions, respectively); while in the open vowels, 58.3% and 69.8% (in the "slow" and the "fast" conditions, respectively) of glottalization was measured.

With respect to the backness of the vowels, in the twofold comparison, the front vowels showed 60.4% of glottalization in the "slow" condition, and 68.7% in the "fast" condition, while in the back vowels these ratios were 52.9% and 64.1% in the "slow" and the "fast" conditions, respectively. In the threefold comparison, the front vowels showed glottalization in 62.4% in the "slow" condition, and in 72.3% in the "fast" condition of all cases labelled as realized with irregular phonation, the central vowels showed glottalization in 57.9% and in 63.6% in the "slow" and in the "fast" conditions, respectively, and the back vowels showed glottalization in 50.0% in the "slow" and 64.2% in the "fast" condition. To summarize, the ratio of glottalization in the "fast" condition exceeded that of the "slow" condition in all vowel groups.

2.3 Discussion

The analysis of pseudo-words in two different speech rate conditions resulted in an unexpected difference between "slow" and "fast" speech, namely that speakers produced a higher frequency of occurrences of initial irregular phonation in vowels in "fast" speech than in "slow" speech. The statistical analysis showed a significant interaction effect of *vowel quality* and *speech rate,* and a further test showed an interaction effect of *vowel height* and *speech rate* on the frequency of occurrence of irregular phonation, revealing that vowels were affected differently by increased speech rate according to their height feature: close vowels were more susceptible to irregular phonation than mid or open vowels. When we analyzed the vowels in a finer three-fold backness contrast, the data also showed a significant *backness* × *speech rate* interaction, revealing that the effect of speech rate increased the frequency of occurrence of irregular phonation in back vowels the most, while central and front vowels did not show a clear and consistent effect.

The ratio of glottal stops (relative to the number of all irregular occurrences) was the highest in the case of close vowels, which can be interpreted as follows: the less probably irregular phonation occurs, the more likely it appears as a glottal stop.

The above mentioned unexpected results raise the question if the experimental design and the material analysed were adequate for the study. The JND-based method and the JND value (borrowed from results for Dutch, see Quené, 2007) we used to objectively define and distinguish (minimally two) speech rate conditions appeared to be suitable and appropriate for our purposes, that is, to reasonably designate groups of speech tempi which may be regarded as different groups (based on their objectively measured speech rate values). However, the criterion for the inclusion of speakers in the analysis may have led to some undesired artefacts in the results. As we defined the threshold of tempo differences on the basis of the averaged values of one speaker, we may have included several tokens of the target items in the analysis which were actually not distinguished by the previously defined threshold. Therefore, we may also have introduced some noise in the data.

As far as the target word is considered in which the target vowels were embedded, other types of complications arose. Since the V*tina* construction starts and ends with a vowel, in its consecutive production, a hiatus position occurs. The hiatus position, however, is not irrelevant to the production of irregular phonation, as it may elicit a higher frequency of occurrence of it (by which the speakers try to avoid this disallowed phonotactic phenomenon; see, e.g., Markó, 2013). Moreover, we also suspect that this effect is not even constant across the conditions, as in slower speech the speakers are more likely to insert longer pauses between the consecutive target words, thus the effect of the hiatus may be greater in fast speech. On this basis, we replicated the experiment with several modifications. First, in Experiment 2 we used real Hungarian words instead of nonsense words. And secondly, these target words were selected to be adequate to retest the effect of the backness and height features of the vowels, while they were also sufficient to avoid the risks of the confounding effect of hiatus, since they ended with a consonant.

3 Experiment 2

3.1 Material and method

3.1.1 Material and experimental design

In Experiment 2, the test material consisted of disyllabic Hungarian pronominal adverbs: *innen* /inːɛn/ 'from here'; *onnan* /onːɒn/ 'from there'; *ennek* /ɛnːɛk/ 'for this'; *annak* /ɒnːɒk/ 'for that'. These adverbs start with four different vowel qualities which vary both in the vowel height (close /i/ vs. mid /o/ vs. open /ɛ ɒ/) and the backness (back /o ɒ/ vs. front /i ɛ/) features (while backness also co-varies with lip spreading) (see Figure 2). (It is important to note here that in Experiment 2, by the introduction of /ɛ/ as an open vowel we used a "simplified" feature set along the vowel height dimension again, to which the system described by Szende (1994) and the similar "acoustic openness" of /ɛ/ and /ɒ/ provided the basis.)

Similarly to Experiment 1, the target words were embedded in a carrier phrase. The phrase used here was the following: *Mondd:* [target word] *kell.* 'Say: [target word] needed'. All of the target vowels were positioned word-initially, thus they bore sentential accent on the first syllable (given that word stress is fixed on the first syllable in Hungarian).

Also similarly to Experiment 1, the stimuli were presented on a computer screen. Each trial consisted of two display screens again: first the introductory part *(Mondd:)* was shown to the participant, then the target item (target word + *kell)* was displayed (refer to Figure 3). The participants' task was to read aloud the target item, but not the introductory part.

In order to elicit speech rate differences between the conditions, the timing of the display screens was manipulated again. However, as the carrier phrase used in Experiment 2 was longer than the one used in Experiment 1, we used a slightly longer timer setting in the "fast" condition than previously. As a result, in the "slow" speech condition, each display screen appeared for 1500 ms resulting in 3000 ms for one trial in total (including the introductory part and the "target word + *kell"* construction) just as in Experiment 1. However, in the "fast" speech condition the timer was set to 500 ms, resulting in 1000 ms for one trial in total. The experimental procedure was the same as in Experiment 1 in other respects. In Experiment 2, 4 vowel qualities/target words × 5 repetitions × 2 speech rate conditions, i.e., 40 vowels per speaker were recorded.

3.1.2 Participants and the control of speech rate

For Experiment 2 only female speakers were recruited; all 33 of them were university students, and native speakers of Hungarian, who reported no hearing or speech deficits. In order to ensure that the "slow" and the "fast" conditions differentiate properly (i.e., they may be differentiated by a conceptually sound value), the JND-based threshold (introduced in Experiment 1) was used again to define speech rate differences. For this purpose, we measured and compared the target item durations both in "slow" and "fast" conditions speakerwise just as in Experiment 1. However, in the present experiment, we decided to apply a higher threshold of 10% to account for the expected reduction in duration variability, since in this study, five repetitions of each item were analyzed and averaged. With this higher threshold we intended to establish a larger gap between the mean durations of the "slow" and the "fast" realizations, that is, to reduce the overlap between the conditions by eliminating most of the vowel realizations which were extremely long in the "fast", or extremely short in the "slow" conditions. We opted for the application of the stricter threshold due to the fact that in Experiment 2 we managed to recruit a higher number of participants than in Experiment 1, so that after the exclusion of speakers whose speech samples were not differentiated by the threshold, the amount of the data was still sufficient for analysis. The threshold was exceeded by the data in the case of 18 participants, thus finally in the main analysis 18 speakers' material was involved (and 15 participants' data were excluded). The speakers' age ranged between 19 and 34 years, with a mean of 24.9 years. The duration difference between the two conditions ranged between 9.6% and 28.5% speakerwise, and the mean of differences was 16.8±5.5% (Figure 10). The overall item duration was 852±107 ms in the "slow" condition, and 705±69 ms in the "fast" condition (for all 18 speakers). (We should also note that in some cases, the participants might have inserted a short pause at the word boundary of *innen/onnan/ennek/annak # kell.* However, as this pause cannot be differentiated reliably from the occlusion phase of the second plosive, we did not identify these possible pauses and regarded the total item duration as item duration in the data.)

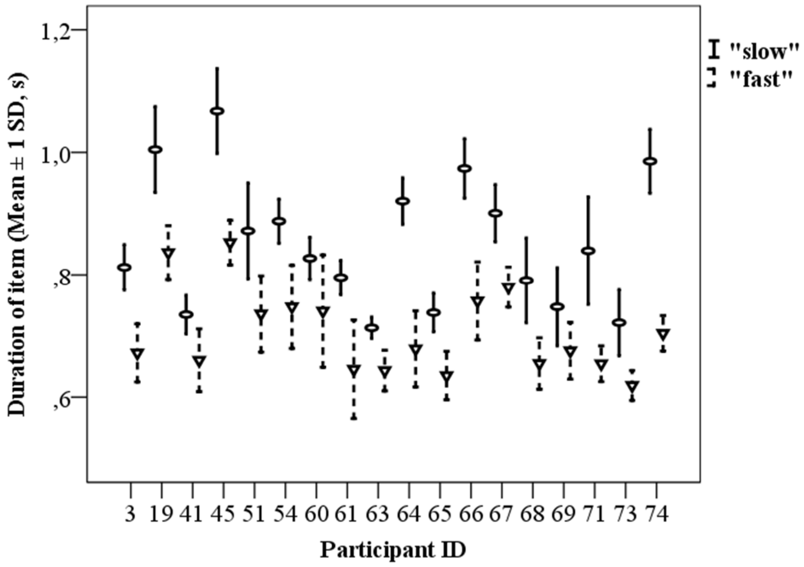

Figure 10.
The duration of items (target word + *kell)* as a function of speech rate conditions, speakerwise (mean ± SD)

3.1.3 Annotation and analysis

In the "slow" condition, 359 vowels were analyzed (as one speaker mispronounced one target word), while in the "fast" condition the number of the analyzed vowels was 360.

The "target word + *kell"* construction, the word-initial vowel, and the irregular phonation at the beginning of the word-initial vowel were labelled manually in Praat (Boersma & Weenink, 2016). The labeling was performed similarly to Experiment 1, and we used the categories of "glottalization" and "glottal stop" again.

We analysed the ratio of vowels produced with irregular phonation with respect to vowel quality, vowel height, backness, and speech rate. As previously, we determined and compared the ratio of glottalized vowel occurrences to the number of all vowels realized with irregular phonation again, and compared it to the ratio of glottal stops in the two speech rate conditions.

Three 2-way repeated measures ANOVAs were performed with the factors (i) *vowel quality* and *speech rate,* (ii) *vowel height* and *speech rate,* and (iii) *backness* and *speech rate* at a confidence level set to 95%.

3.2 Results

3.2.1 Initial irregular phonation as a function of vowel quality and speech rate

The ratio of vowels produced with irregular phonation (pooled over speakers) as a function of vowel quality and speech rate is presented in Figure 11.

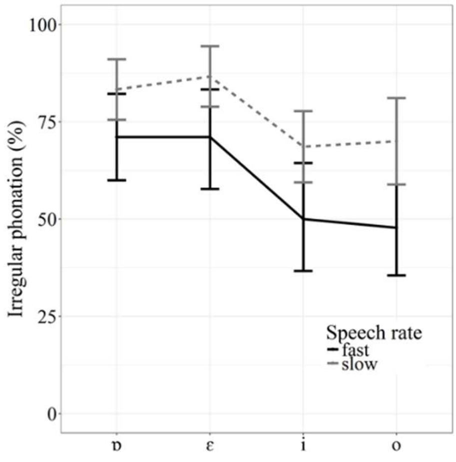

Figure 11.
The ratio of vowels produced with any kind of irregular phonation as a function of vowel quality and speech rate (mean + 95% CI)

In the "slow" condition, the ratio of initial irregular phonation in the front close /i/ was 68.6±20.7%, while in the "fast" condition it was 50.0±30.1% of all cases. In the case of the front open vowel /ɛ/ these ratios were 86.7±18.1% in the "slow" and 71.1±29.3% in the "fast" conditions. The back mid vowel /o/ was produced with irregular phonation in 70.0±24.0% of all cases in the "slow" and in 47.8±25.8% of all cases in the "fast" condition. Finally, the back open /ɒ/ showed 83.3±18.5% of irregular occurrences in the "slow", and 71.1±24.9% in the "fast" condition.

The ANOVA showed significant main effects of both *speech rate* ($F(1, 17) = 17.38$, $p < 0.001$) and *vowel quality* ($F(3, 51) = 10.56$, $p < 0.001$), but the interaction of these factors turned out to be non-significant.

3.2.2 Initial irregular phonation as a function of backness and speech rate

The ratio of vowels produced with irregular phonation as a function of backness and speech rate is shown in Figure 12.

The back /o/ and /ɒ/ and the front /ɛ/ and /i/ vowels were produced with irregular phonation in a similar ratio both in the "slow" and the "fast" conditions. In the "slow" condition front vowels showed 77.6±21.2% ratio of irregular occurrences, while back vowels showed 76.7±22.1% of all cases. In the "fast" condition the ratios were 60.6±31.2% and 59.4±27.7%, respectively. Regarding this comparison, statistical analysis showed a significant difference between the *speech rate* conditions ($F(1, 68) = 14.58$, $p < 0.001$), but not between the front and back vowel groups. We must note here that as in the present analysis no central vowels are involved, we could not apply the three-fold analysis of vowel backness we presented in Experiment 1.

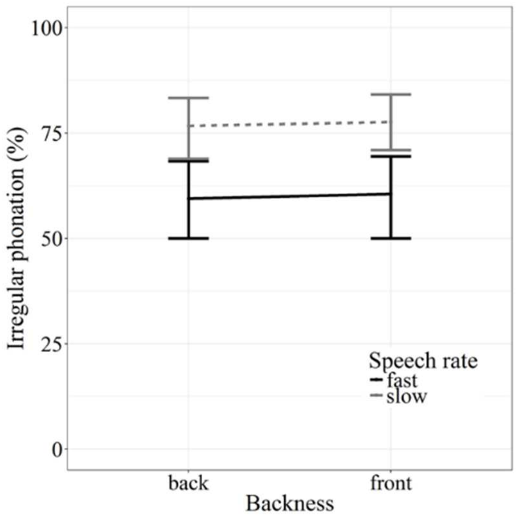

Figure 12.
The ratio of vowels produced with any kind of irregular phonation as a function of backness and speech rate (mean + 95% CI)

3.2.3 Initial irregular phonation as a function of vowel height and speech rate

The ratios of vowel realizations with irregular phonation in terms of vowel height and speech rate are shown in Figure 13. The close vowel /i/ was produced with irregular phonation in 68.6±20.7% of all cases in the "slow" and in 50.0±30.1% of all cases in the "fast" condition. The mid vowel /o/ showed initial irregular phonation in 70.0±24.0% of all cases in the "slow" and in 47.8±25.8% in the "fast" condition. The open vowels /ɒ/ and /ɛ/ were produced with irregular phonation at the highest ratio: in 85.0±18.1% in the "slow" and in 71.1±26.8% in the "fast" condition.

According to the ANOVA, there was no significant interaction between *speech rate* and *vowel height* but both factors had a significant main effect (*vowel height:* $F(2, 34) = 13.20, p < 0.001$; *speech rate:* $F(2, 17) = 17.28, p < 0.001$).

3.2.4 Ratio of glottalization and glottal stops as a function of vowel quality and speech rate

The ratios of occurrence of glottal stops and glottalization as a function of vowel quality and speech rate are presented in Figure 14. Relative to the number of all irregular occurrences both in the "slow" and the "fast" conditions, the ratio of glottalization (54.9% and 56.6.0% of all irregular occurrences, respectively) exceeded the ratio of glottal stops (45.1% and 43.4% of all irregular occurrences, respectively) as well.

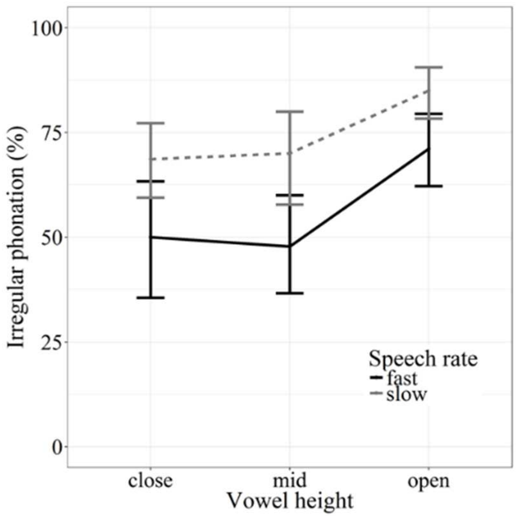

Figure 13.
The ratio of vowels produced with any kind of irregular phonation
as a function of vowel height and speech rate (mean + 95% CI)

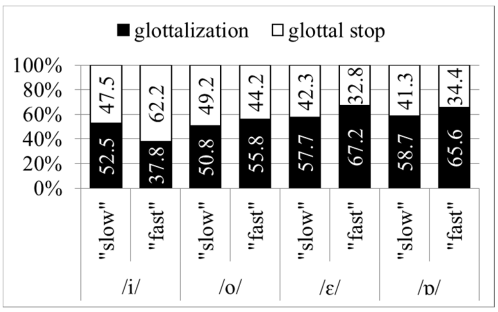

Figure 14.
The ratio of the two types of irregular phonation
(relative to all irregular occurrences) as a function of vowel quality and speech rate

The ratios of glottalization and glottal stops were close to equal in the case of /i/ in the "slow" condition (52.5% vs. 47.5%, respectively), while in the "fast" condition the ratio of glottal stops (62.2%) was well above the ratio of glottalization (37.8%). For the "slow" condition the pattern was very similar in the case of /o/ (50.8% and 49.2% for glottalization and glottal stops, respectively); in the "fast" condition, however, glottalization (55.8%) was relatively more frequent than glottal stops (44.2%). In the case of /ɛ/ and /ɒ/, the ratio of glottalization exceeded the ratio of glottal stops in both of the conditions: it was 57.7% in /ɛ/ and 58.7% in /ɒ/ in the "slow" condition, and 58.7% in /ɛ/ and 65.6% in /ɒ/ in the "fast" condition. Although we observed differences in the glottalization to glottal stop ratio between the two conditions in three of the four analyzed vowels, the close /i/ showed the opposite tendency with the change in speech rate to that observed in the case of open vowels. The direction of the change in the mid /o/ was the same as in the case of the open vowels, but the degree of change was smaller.

3.3 Discussion

In Experiment 2 four vowel qualities of Hungarian embedded into real words were analysed in "slow" and "fast" speech rate conditions in terms of the frequency of occurrence of irregular phonation. We found significant effects of the *speech rate, vowel quality* and *vowel height* factors, while the factor *backness* (expressed in a twofold opposition) did not affect the data. The relative ratio of glottalization and glottal stops showed similar patterns as observed in Experiment 1. Thus we can conclude that in real Hungarian words embedded in non-facilitatory contexts of irregular phonation, the increased speech rate decreased the frequency of occurrence of vowels realized with irregular phonation in general, while the ratio of glottalization among these occurrences increased in all vowels but /i/ as speech rate increased.

4 General discussion and conclusions

In the two experiments reported in the present paper, we first tested the hypothesis that the frequency of occurrence of irregular phonation is higher in slow than in fast speech. Although, in this respect, the first experiment contradicted our expectations, in the second experiment, we eliminated some confounding factors (i.e., hiatus position) which may have affected the data in Experiment 1 in an undesired way, and we corroborated the hypothesis. Our second hypothesis may be regarded to be partially confirmed by the data: even though backness was not shown to have a significant effect on vowel-initial irregular phonation when it was expressed in the traditional twofold opposition (front vs. back) (in Experiment 1 and Experiment 2), the less traditional threefold analysis (front vs. central vs. back) revealed that there is an effect observable in a numerically well-balanced comparison (in Experiment 1). According to this latter analysis, central and front vowels differed from back vowels in terms of their susceptibility to irregular phonation in slow speech. That is, while we observed a high number of vowel realizations with irregular phonation in basically all of the vowels in fast speech (irrespective of their backness), in slow speech, back vowels exhibited a much smaller number of realizations with irregularity in the voice source than central and front ones did. This effect, however, was observed only in Experiment 1, where the threefold recategorization was possible (as opposed to Experiment 2, where only the twofold-contrast categorization was attainable). In line with expectations, we also showed that open vowels favor irregular phonation more than mid and close ones both in slow and fast speech which finding corroborated our third hypothesis. Our fourth assumption claiming that faster speech rates reduce the relative amount of glottal stops, while increasing the frequency of occurrence of glottalization was not verified, since glottalization was more frequent in both speech rate conditions we studied. However, to some extent, at the different vowel heights studied, different tendencies were found. In Experiment 1, the vowel /u/, while in Experiment 2, the vowel /i/ appeared to be exceptions to some generally observed tendencies: in these vowels' cases the ratio of glottal stops was well above the ratio of glottalization, for /u/ in the "slow", while for /i/ in the "fast" condition. These results may suggest that the behaviour of close vowels is different from that of mid and open vowels with respect to the form of irregular phonation they elicit.

Considering that in the present study the effect of phonetic position, vowel quality, and speech rate were strictly controlled for and investigated, we can conclude that open vowels tend to elicit irregular phonation more than mid and close ones do, irrespective of backness. We can also conclude that the frequency of irregular phonation tends to be lower in fast than in slow speech (or at least in speech rate increased under laboratory conditions). The relative frequency of glottalization to glottal stops in phrase-initial position did not appear to be influenced by speech rate in general, which itself is inconsistent with the claims of earlier studies (e.g., Malisz et al., 2013). However, taking the analysed vowels separately into account, we observed that the behaviour of the close /i/ was opposite to that of the open /ɒ/ and /ɛ/. While the open vowels showed the widely documented tendency of being realized with relatively fewer glottal stops in fast speech, /i/ was produced with a relatively higher ratio of glottal stops under the same conditions. This result suggests that vowel height has an effect not only on the frequency of irregular phonation but also on the manner of its realization in the case of word- and phrase-initial vowels.

Acknowledgements

The authors are grateful to Gergely Varjasi for his valuable help in recruitment of the participants and in conducting the experiments.

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