WORD-INITIAL GLOTTAL MARKING IN HUNGARIAN AS A FUNCTION OF ARTICULATION RATE AND WORD CLASS

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Abstract
The present study's aim was to analyse the glottal marking of word-initial vowels in two speech styles, reading aloud and spontaneous speech, based on 12 speakers' Hungarian speech. In earlier studies of other languages (English, German and Polish), it was suggested that among several other factors, speech style, speech rate, vowel quality and word type had an effect on the glottal marking of word-initial vowels. In the Hungarian corpus analysed, speakers produced glottal marking significantly less frequently in spontaneous speech than in reading aloud. Both slower articulatory rate in the "carrier" pause-to-pause interval, and longer vowel duration went hand in hand with glottal marking. All the features of vowel quality were analysed, but only vowel height was found to play some minor role in glottal marking, while backness and rounding did not at all. In reading aloud, low and mid vowels were less frequently glottalized than high ones, while in spontaneous speech, high vowels were less frequently glottally marked than the other ones. The factor of vowel height played a significant role only in this latter speech style. Slower articulation proved to enhance the possibility of glottal marking in word-initial vowels in our study as well, in accordance with our hypothesis. With respect to word type (content vs. function words), our data imply that lexical prominence does not have an effect on the glottal marking of word-initial vowels in Hungarian. Alternatively, it can be supposed that phrase-initial position has a prevalent effect which overrides the effect of word type.

Keywords: glottal marking, word-initial vowels, reading aloud, spontaneous speech, articulation rate, word class

1 Introduction

Phonation results from vocal fold vibration. This vibration is usually quasiperiodic, leading to modal phonation; however, inconsistency may also appear. The phenomenon goes by several names, e.g., *irregular phonation, creaky voice, glottalization, laryngealization, vocal fry.* Whichever term is used, it is an umbrella term, as the vibration can be aperiodic in several ways: the timing or amplitude of adjacent periods may exceed the normal ranges of jitter and shimmer (e.g., Surana & Slifka, 2006), or their wide-spacing may be

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atypical. For instance, Batliner et al. (1993) distinguished six types of laryngealization in approx. 30 minutes of spontaneous and read speech by four speakers. Dilley et al. (1996) studied texts read out by five speakers in radio news programs with respect to irregular voice quality (glottalization) occurring in word-initial vowels. They defined four types of realizations. Some researchers also analyse the glottal stop in this context (e.g., Dilley et al., 1996). Therefore it is not always clear which terms refer to which types of irregular phonation, or which terms are treated as synonyms.

The functions of irregular phonation vary across languages. In some languages, it expresses a phonological contrast – mostly it distinguishes pairs of sonorants from one another (for instance, in Mazateco, spoken in Mexico, it distinguishes vowels, and in some North-American Indian languages it distinguishes nasals); less frequently (e.g., in Hausa) distinguishing obstruents (see e.g., Gordon & Ladefoged, 2001). In several dialects of English, irregular phonation distinguishes allophones of syllable-final /t/ and /p/ (Pierrehumbert & Talkin, 1992).

Several researchers have investigated the role of irregular phonation in expressing emotions and/or attempted to use it in the automatic recognition of emotions (e.g., Batliner et al., 2007; Gobl & Ní Chasaide, 2003). The socio-cultural role of irregular phonation has also been demonstrated in an experiment involving young American women (Yuasa, 2010), and its conversational function has also been noted in English, where the realization of *yeah* with modal vs. irregular phonation is associated with distinct functions by the speaker (and the listener) (Grivičić & Nilep, 2004).

Studies revealed that prosodic factors are also linked to irregular phonation. Phrase boundary and/or stress elicit glottal marking at a higher rate (e.g., Umeda, 1978; Dilley et al., 1996; Rodgers, 1999; Kohler, 2001).

Rodgers (1999) found in German that glottalization is more frequent in content words than in function words (he defined content words as words with lexical meaning, and function words as words with grammatical meaning, based on Matthews, 1997) both in read and spontaneous speech. According to his interpretation, this difference may be partly due to the widely observed fact that content words can be accented in a relatively high ratio, while function words are typically unaccented. Rodgers (1999) also found that the frequency of occurrence of glottalization is higher in read speech than in spontaneous speech.

Speech rate also turned out to influence glottal marking: in slower speech, higher rates of glottal marking were observed than in faster speech (see e.g., Pompino-Marschall & Żygis, 2010; Malisz et al., 2013).

The occurrence of irregular phonation was found to show gender-related differences in many speech communities. A number of studies have found irregular phonation to predominate among male speakers (e.g., Esling, 1978 in

Edinburgh; Henton & Bladon, 1988 for speakers of RP and 'Modified Northern' English; Stuart-Smith, 1999 in Glasgow); however, the opposite tendency is also documented in the literature (e.g., Yuasa, 2010; Markó, 2013; Podesva, 2013).

It is also well known that the frequency of occurrence of irregular phonation is speaker dependent to a large extent. Some speakers hardly produce any irregular voicing, while some produce it fairly frequently (Umeda, 1978; Henton & Bladon, 1988; Dilley et al., 1996; Redi & Shattuck-Hufnagel, 2001; Slifka, 2006; for Hungarian: Bőhm & Ujváry, 2008; Markó, 2013). Therefore, the presence of glottalization has an eminent role in human speaker recognition (Bőhm & Shattuck-Hufnagel, 2007). It was also shown that the less speakers glottalize, the more probable it is that they do so at a phrase-, word- or vowel-to-vowel boundary position (Markó, 2013).

Kohler (2001, pp. 282-285) defined four types of 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 beginning with vowels.
(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) Paralinguistic function of glottalization phenomena at the utterance level which comprise
    (i) phrase-final relaxation of phonation, and
    (ii) truncation glottalization, i.e., utterance-internal tensing of phonation at utterance breaks.

The present paper focuses on vowel-related glottalization phenomena (see above under (1)) in the case of word-initial vowels in Hungarian. The effect of vowel quality (especially vowel height) on the frequency of glottalization appears to prevail independently of the language, as it has a physiological background: in low/back vowels, the tongue is pulled back, and due to their mechanical links, the larynx is in a lower position (Moisik & Esling, 2011; Lancia & Grawunder, 2014). Therefore low/back vowels can elicit glottalization at a higher rate than close/front ones. This effect has also been demonstrated in Hungarian (Markó et al., 2018a).

The glottal marking of word-initial vowels was analysed in several earlier studies (e.g., Umeda, 1978; Rodgers, 1999; Redi & Shattuck-Hufnagel, 2001; Pompino-Marschall & Żygis, 2010) both in reading aloud and spontaneous speech, but mainly on English and German. More recently, Malisz et al. (2013) published a paper comparing German and Polish and highlighting the question if the rhythm characteristics of the given language have an effect on the appearance of glottal marking in the case of word-initial vowels. Both languages show vowel-related glottal marking, and neither of them treats the glottal stop as a

member of the phoneme inventory or an allophone. However, their rhythmical characteristics are different. Whereas German is unambiguously a stress-timed language with a mobile lexical stress pattern, the rhythmical status of Polish is debated (for details, see Malisz et al., 2013). Polish assigns fixed lexical stress to the penultimate syllable (with few exceptions), and as word stress is predictable, it is considered to be acoustically weak. According to the literature, in Polish, duration does not contribute to the expression of prominence, while in German word stress is represented primarily by duration at the lexical level. In the case of phrase level prominence, both languages apply changes in fundamental frequency, intensity and duration. While German is an inflected language, Polish is agglutinative with some inflecting characteristics. Malisz et al. (2013) summarized the relevant literature on glottal marking in German and Polish. In German, stressed and/or accented syllables, low vowels and content words (compared to function words) favour glottal marking. As for Polish, glottal stop was found in emphatic and boundary marking functions, the latter prevailing at the boundary of a prefix and a vowel-initial stem, and this pattern was more typical in the case of rare words than in frequent ones. In Polish, glottal marking was found to be more frequent in function words; however, it was not independent from prosodic phrase structure (with phrase-initial function words predominating in this pattern).

In the analysis of Malisz et al. (2013), both spontaneous and "prepared" speech were involved. The spontaneous subcorpus consisted of material from six instruction-givers of a Polish task-oriented dialogue corpus (202 word-initial vowels), and the utterances of four storytellers of a German spontaneous dialogue corpus (401 word-initial vowels). The gender of the speakers is not mentioned in the main text of the paper; however, Appendix A specifies that the German spontaneous subcorpus involved 2 female and 2 male speakers, compared to 3 female and 3 male speakers in the Polish spontaneous subcorpus. The "prepared" speech material consisted of public speeches of 4 Polish and 4 German "prominent speakers", mainly politicians, and all of them were males (472 Polish and 885 German word-initial vowels).

Polish speeches were found stress-timed, while Polish dialogues turned out to be syllable-timed. In the German material, both the prepared and the spontaneous subcorpora were measured as stress-timed. The results of the study showed that on word-initial vowels, glottal marking occurred more frequently in German (63.4%) than in Polish (45%). In German, glottal marking had a higher share in spontaneous speech (72.5%) than in prepared speech (59%), similarly to the situation in Polish (53.5% in spontaneous speech and 41.5% in prepared speech). In both languages, the majority of prominent vowels were glottally marked, and vowel height correlated with glottal marking, namely low vowels were marked glottally in a higher ratio. With respect to word type (content vs.

function words) opposite tendencies were found in the two languages. In Polish, function words were glottalized in a higher ratio (50% compared to 37.7% of content words), in contrast with German, where content words showed a higher ratio of glottal marking (77.3% compared to 57% of function words). However, in phrase-initial position, content words received more glottal marking than function words in the same position, even in Polish.

In the present paper, we analyse glottal marking in word-initial vowels in Hungarian spontaneous and read speech. Glottal marking is used here as an umbrella term in reference to any kind of irregularity in the vocal source, including glottal stop. By way of introduction, it is worth highlighting some relevant characteristics of Hungarian.

The Hungarian vowel system consists of 14 vowels 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.

According to the traditional view, 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 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 behaviour, namely its participation in vowel harmony) both by the phonological (e.g., Siptár & Törkenczy, 2000) and the phonetic literature (e.g., Kassai, 1998; Gósy, 2004). Note, however, that on the basis of an 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.

In the traditional view, again, Hungarian 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 (Kassai, 1998; Gósy, 2004). 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/. (In the present paper, we adhere to the latter notation and analysis.)

Hungarian is an agglutinative and syllable-timed language. At the lexical level, stress is highly predictable, assigned to the initial syllable of a content word, therefore word-level stress is non-distinctive (Szende, 1999). Lexical stress is considered to be expressed primarily by vowel duration (Szalontai et al., 2016; Mády et al., 2017). Hungarian is an obligatory syntactic focus marking language, which means (among other things) that in the case of narrow focus, the focused constituent shows the highest prominence, while the ensuing elements are deaccented. Narrow focus elements appear in particular syntactic

positions. Due to the close interrelations between syntax and accent distribution, several studies have argued that prosodic means do not play an important role in prominence marking in Hungarian, as suggested by evidence from both laboratory and spontaneous speech (Mády, 2012; Markó, 2012). However, some studies did find phonetic markers of focus prominence in Hungarian (Genzel et al., 2015; Szalontai et al., 2016; Mády et al., 2017). In particular, changes in fundamental frequency and duration were identified as strong predictors of prominence.

In Hungarian, various boundary marking functions of irregular phonation have been thoroughly investigated; however, many aspects of word-initial vowel-related glottal marking have not received a systematic analysis. The aim of the present study is to analyse some of the factors (speech style, vowel quality, speech rate, and word type) in Hungarian, which have been claimed to have an effect on the frequency of occurrence of vowel-related glottalization in word-initial position. Word type as a variable has never been introduced to the analysis of Hungarian before, and comparisons of spontaneous and read speech have not focused on vowel-related glottal marking. The effect of speech rate and vowel quality have only been analysed in systematically varied short stretches of laboratory speech (Markó et al., 2018a), with no pertinent data either from read speech or from spontaneous speech. Moreover, the results for German and Polish mentioned above (Malisz et al., 2013) invite cross-linguistic comparison.

Most of the studies of irregular phonation in Hungarian have used the spoken language database called BEA (see Gósy, 2012), which includes both spontaneous and read speech samples from the same speakers. The material of the present study also comes from this database (for details, see below).

Our hypotheses were formulated based on the previous literature on other languages, but not without taking into account the differences between Hungarian and languages that are well-studied in terms of glottal marking. With respect to speech style, in line with Rodgers (1999), our hypothesis was that the frequency of occurrence of glottal marking would be higher in read speech than in spontaneous speech. Read speech was expected to be more carefully produced, more fluent, and lacking hesitations. Besides, the text of read speech has a predetermined structure; therefore its organization might be more clearly marked by phonetic means such as glottal marking.

With respect to vowel quality, we analysed vowel height, backness and lip rounding separately. In line with earlier findings, we assumed that low vowels would show a higher rate of glottal marking than mid and high ones. Nevertheless, in terms of backness, previous results did not show an unambiguous pattern. In a study on Hungarian word-initial vowel-related glottalization (Markó et al., 2018a), the feature of backness was subjected to both twofold (front vs. back, see e.g., Gósy, 2004) and threefold comparisons

(front vs. central vs. back, see Bolla, 1995). While in the twofold comparison, the front vowels /i y eː ø ɛ/ and the back ones /u o ɒ aː/ were not distinguished by the frequency of glottal marking, the threefold comparison detected a significant difference between the front /i eː ɛ/ and the central /y ø aː/ versus the back /u o ɒ/ vowels, namely the last group elicited a higher ratio of glottal marking than the first two. Therefore, in the present study, /i y eː ø ɛ aː/ were considered as front vowels, while /u o ɒ/ were considered as back vowels (see also Gósy & Siptár, 2015).

Regarding the effect of speech rate, similarly to several earlier studies (e.g., Malisz et al., 2013), faster speech was assumed to reduce the frequency of glottal marking in word-initial vowels relative to slow speech.

In terms of word type, the previous results based mainly on German and Polish have mixed implications. Function words are non-prominent in general, and stress has been shown to correlate with glottal marking by several studies. Phrase-initial position, however, elicits glottalization at a higher rate. Considering that in Hungarian, the most frequent function words are the definite and indefinite articles (*a/az* 'the' and *egy* 'a(n)'), which begin with low/mid-low vowel and are typically positioned at the beginning of phrases (similarly to Polish), we did not expect word type to predict glottal marking.

2 Methods

2.1 Material

This study presents our results on read and spontaneous speech. The two subcorpora were chosen from the BEA database (Gósy et al., 2012). The database consists of various speech types, including both spontaneous and read speech. We analysed the spontaneous speech type, featuring texts in which the speakers talk about their lives, i.e. school years, jobs, hobbies, etc. This task involves a quasi-monologue, with the interviewer only asking questions if the subject seems to talk too little. As read material, we selected the sentence reading task of this database for our study. In this task, subjects read aloud 25 sentences of various lengths and syntactic structures; however, all are declarative sentences.

Texts added to the database are recorded under invariant circumstances. An AT4040 microphone is used, the speech is recorded digitally at 44 kHz and 16 bits.

All 25 sentences were labelled in the read speech material from each speaker, but in the case of very long spontaneous speech samples only the first appr. 4-5 minutes were labelled. This way, a total duration of 55.2 minutes of analyzed spontaneous speech was produced.

2.2 Subjects

The database collects speech of monolingual speakers of standard Hungarian. In Hungarian females' speech, glottalization was found more frequent than with male speakers of the same age groups (see Markó, 2013). Considering that gender may have an effect on glottal marking, the same number of female and male speakers (six from both genders) were chosen from the database: three young female (22 to 24 years), three young male (20 to 24 years), three middle age female (44 to 45 years) and three middle age male (39 to 45 years) speakers. None of them reported any hearing impairment or speech disorders. Both the reading and the spontaneous speech material of these speakers were used, i.e., the speakers in the two subcorpora were the same.

2.3 Data collection

Both the spontaneous speech samples and the readings were labelled in Praat (Boersma & Weenink, 2017). Three levels of labels were used (Figure 1). In the first tier, the pause-to-pause intervals of the subjects were transcribed for articulatory rate calculations. In the second tier, the words starting vowels of any kind were labelled. In these labels, the vowel quality, the word type (content or function word), and any possible further information were noted. In the third tier, each word-initial vowel was labelled and information on its glottal marking was included.

Cases where the glottal marking appeared only later, not at the start of the vowel, were not considered as being glottally marked due to their word-initial position. Besides, the cases where two phonemes of the same vowel quality met in a hiatus across word boundary and their boundaries could not be established were eliminated from the analysis. (For example: *ütötte el* /ytøtːɛ ɛl/ 'he spent (his time)'.

The following data were retrieved from the three labels by a Praat script:

(i) all words that start with any kind of vowel;
(ii) the type of the word (content or function word);
(iii) the initial vowel;
(iv) the duration of the initial vowel;
(v) the presence of glottal marking at the beginning of the vowel;
(vi) the duration of the relevant pause-to-pause intervals;
(vii) the quasi-phonetic transcript (one speech sound is represented by one character) of speech in the intervals.

In the analyses of vowel height, mid-low and low vowels were pooled (similarly to Markó et al., 2018a), therefore, we differentiated three levels of vowel height: high /i y u/, mid /eː ø o/ and low /ɛ ɒ aː/.

In the analysis of backness (based on the results of Markó et al., 2018a), /i y eː ø ɛ aː/ were considered as front vowels, while /u o ɒ/ were considered as back vowels in the present study. The vowel /aː/ is ambiguous regarding the feature of

backness, since /aː/ phonologically alternates with back /ɒ/; however, its phonetic position is central or front. As we hypothesized that glottal marking was related to articulatory phonetic properties, we analyzed /aː/ together with the front vowels (as we mentioned above).

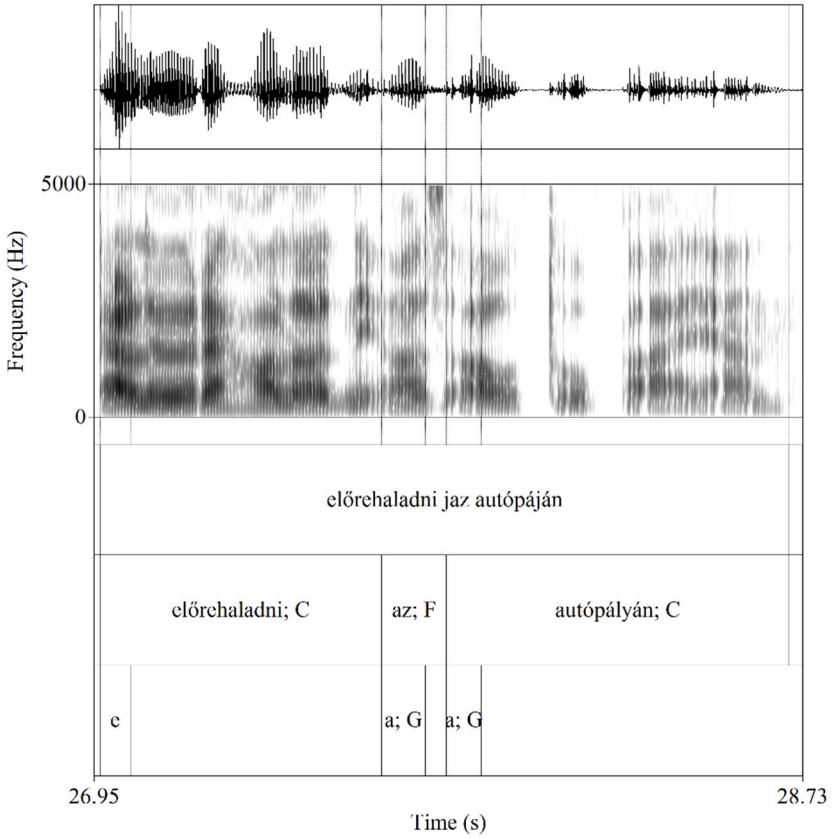

Figure 1.
Labeling sample. Reading task:
*A forgalom miatt csak nehezen lehetett **előrehaladni az autópályán.***
[ɛløːrɛhɒlɒdniʲ ɒz ɒutoːpaːjaːn]
'The traffic allowed only slow **proceeding on the highway.'**
(F = function word, C = content word; G = glottal marking)

The feature of lip rounding was analysed in accordance with the traditional view (e.g., Gósy, 2004): /y u ø o ɒ/ were considered as rounded, /i eː ɛ aː/ were considered as unrounded vowels. (Rounding partly co-varies with backness in the sense that all back vowels are rounded.)

Although Hungarian is a language with vowel quantity oppositions, we ignored this feature because of the skewed frequency of phonemes in this

language. In particular, high long vowels appear rarely in spontaneous speech and in non-phonetically compiled texts (e.g., Gósy, 2004). Also, quantity pairs of low vowels do not only differ in their duration but also in phonetic vowel height and other features. So, finally 9 vowel qualities were involved in the analyses, irrespective of their quantity (/i y eː ø ɛ aː u o ɒ/). However, the duration of the vowels was analysed with respect to the possible interrelation between duration and glottal marking.

2.4 Analyses and statistical methods

As noted in the Introduction, our question was whether and how speech style, vowel quality, word type and temporal factors affect the appearance of glottal marking in word-initial vowels. Therefore we analysed the interrelations of glottal marking with the quality and duration of the vowel, with word type, and with the articulatory rate of the carrier pause-to-pause interval in both speech styles. Only those intervals were used that included at least one word starting with a vowel. The analysis was carried out in two ways. As first we considered the measured articulatory rate as a scale variable, then we grouped the intervals in two ways: in a twofold and in a threefold comparison. In both comparisons only those pause-to-pause intervals were considered in which at least one word-initial vowel appeared (i.e., intervals in which all words started with consonants were excluded). In the twofold comparison, slow and fast categories were differentiated, while in the threefold comparison categories of (i) "slow", (ii) "medium" and (iii) "fast" were distinguished. In both the twofold and the threefold comparisons, the intervals belonging to different tempo categories were differentiated based on K-means Cluster analyses with iteration set to 20.

In order to test the statistical relevance of the factors in question, we carried out GLMM (General Linear Mixed Models), repeated measures ANOVA, Wilcoxon-test and Pearson's correlation. In order to test the effect of categorical factors on the appearance of glottal marking, the fixed factors in our GLMM model were *speech style, gender, vowel height, backness, rounding, word type,* and *articulatory rate clusters* (with both twofold and threefold clustering subjected to statistical analysis). In addition, these factors were also applied to the two speech styles separately. Scalar variables, i.e., *articulatory rate* and *vowel duration* were tested by GLMM, with glottal marking set as an independent variable. Repeated measures ANOVA was used to measure the statistical relevance of factors across and within speech styles.

Wilcoxon-test was used to compare the ratio of glottal marking in the three temporal clusters. Finally, Pearson's correlation was used to establish whether there was any correlation (i) between the average ratio of glottal marking and average articulatory rate of speakers, (ii) between average ratio of glottal marking and average vowel duration in the case of each speaker, and

(iii) between the ratios (in percentages) of glottal marking when the two speech styles are compared.

3 Results

3.1 General distributions in the corpora

Altogether 860 words starting with any kind of vowel were analysed in the read speech material of the 12 subjects, while 2288 items were found in their spontaneous speech samples. In the spontaneous subcorpus, the analysed vowels were glottally marked in 33.5±8.9%, while in the read speech material this ratio was higher: 54.1±11.5%. Although the distributions of the vowels and word classes analysed were different in the two speech styles, all speakers produced glottal marking more frequently in their read material than in spontaneous speech (the difference between the two speech styles varied between 11.4% and 60.6% speakerwise). This difference was significant ($F(1, 3130) = 44.594$, $p < 0.001$).

3.1.1 Interspeaker differences

Irregular phonation in general (not only in word-initial vowels) is known to be highly speaker- and gender-dependent. These patterns are also apparent in Hungarian (see e.g., Bőhm & Ujvári, 2008; Markó, 2013). Regarding the gender-specificity of the phenomenon, Markó (2013) found that female speakers produce this type of phonation more frequently than their male counterparts. The glottal marking of Hungarian word-initial vowels has not been analysed yet with regard to the subjects' gender. Therefore as a first step we checked the interspeaker and the gender-related variation of the data in our subcorpora.

The frequency of glottal marking in word-initial vowels varied between 26.9% and 74.0% in reading aloud, and between 17.5% and 54.5% in spontaneous speech. As already mentioned above, the standard deviations were not high and did not show large differences (reading: 11.5%, spontaneous speech: 8.9%), that is, interspeaker variability can be considered as moderate. Although the distribution of the various vowel qualities was not balanced within and across the subcorpora as a consequence of the inherent features of the two speech styles, speakerwise correlation was detected between the ratios of glottal marking in the two speech styles (Pearson's correlation: $r^2 = 0.606$, $p = 0.037$). This means that if a speaker produced less glottal marking in one speech style, s/he also produced less in the other one.

In order to see if there was any gender-specificity in our data, we calculated the mean and SD for the two gender groups (Figure 2). The female subjects produced glottal marking more frequently in both speech styles (reading aloud: 57.4±13.8%, spontaneous speech: 38.5±7.6%) than the male ones (reading aloud: 50.9±9.2%, spontaneous speech: 28.6±6.8%). In reading aloud, this

difference was somewhat lower than in spontaneous speech. The differences between the genders are significant in general ($F(1, 3130) = 44.594$, $p < 0.001$).

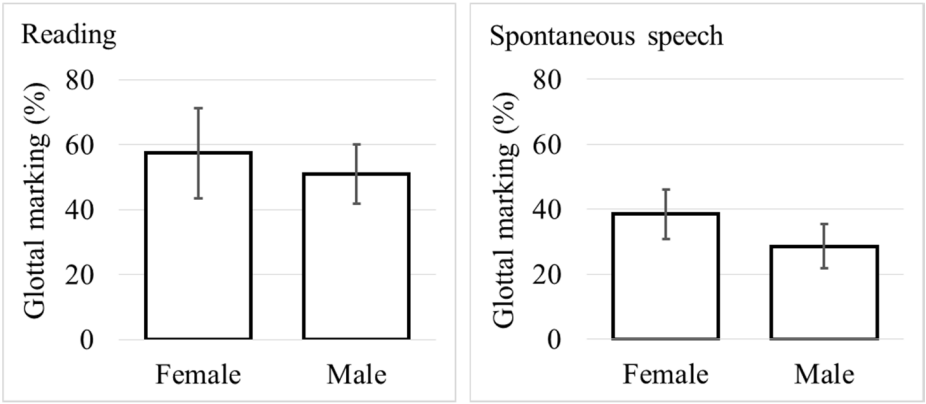

Figure 2.
Ratio of glottal marking in the word-initial vowels
as a function of gender
in reading aloud (left) and in spontaneous speech (right)

3.2 Vowel quality

3.2.1 Vowel height

Vowel height showed different tendencies in the two subcorpora (Figure 3). In reading aloud, the high vowels showed glottal marking in 60.2±16.1%, the mid ones in 61.7±18.6%, and the low ones in 52.5±11.8%. In spontaneous speech, the lowest ratio of glottal marking appeared in high vowels (26.2±7.1%), with mid and low ones not showing any difference (35.3±11.5%, 35.4±9.2%, respectively). Vowel height in itself did not have a significant effect on the frequency of glottal marking ($F(2, 3130) = 0.836$, $p = 0.434$) in general. However, this variation of the ratio of glottal marking varied significantly in the spontaneous speech subcorpus (repeated measures ANOVA: Wilks' $\lambda = 0.340$, $F(2, 11) = 9.713$, $p = 0.005$), while in reading aloud the results did not reveal significant differences among the analysed vowel categories (repeated measures ANOVA: Wilks' $\lambda = 0.594$, $F(2, 11) = 3.411$, $p = 0.074$). When analysing the results speaker by speaker, we can conclude that most subjects followed the tendency that was apparent in the given speech style, or showed no difference (< 10%) as a function of vowel height. In read speech, however, one person exceptionally departed from the general tendencies.

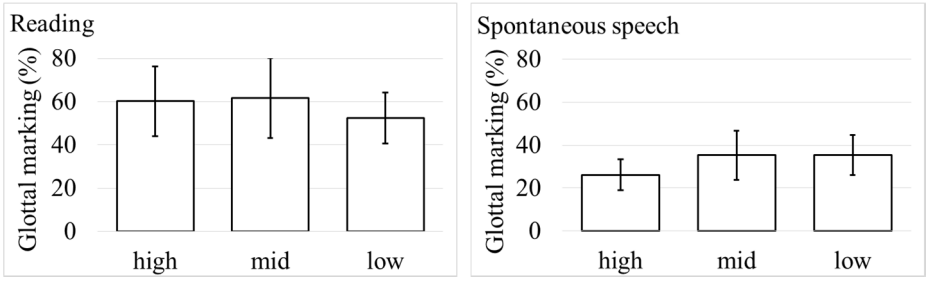

Figure 3.
Ratio of glottal marking in word-initial vowels
as a function of vowel height (mean and SD)
in reading aloud (left) and in spontaneous speech (right)

3.2.2 Vowel backness

The glottal marking of word-initial vowels did not show any tendencies related to vowel backness in either speech style. In reading aloud, three subjects produced glottal marking more frequently in back vowels, while five subjects produced more glottal marking in front vowels. In the case of four speakers, there was no difference (< 10%) in terms of frequency of glottal marking between the back and front vowels. In the spontaneous subcorpus, seven subjects produced more glottal marking in back vowels, three subjects in front vowels, and in the case of two speakers, the vowels did not show any difference (< 10%) in terms of glottal marking as a function of backness. There was no evidence of intraspeaker tendencies either. Speaker-specific differences led to a similar ratio of glottal marking in back and front vowels in both speech styles (Figure 4). In reading aloud, front vowels showed glottal marking in 55.3±7.3%), and back vowels in 53.3±15.5%. In spontaneous speech these ratios were 33.0±10.4% and 33.8±7.8%, respectively. These differences are not statistically significant (in general: $F(1, 3130) = 1.021$, $p = 0.312$, between the speech styles: $F(1, 3130) = 0.014$, $p = 0.907$).

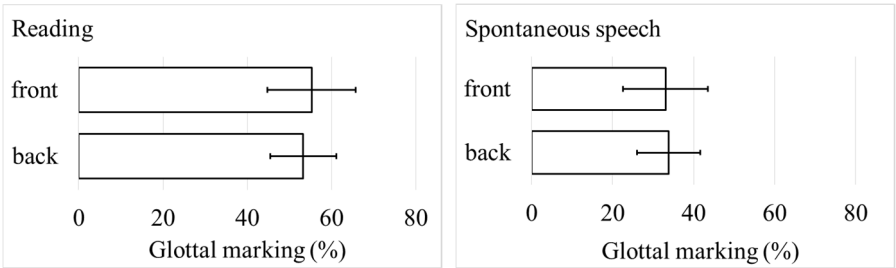

Figure 4.
Ratio of glottal marking in word-initial vowels
as a function of backness
in reading aloud (left) and in spontaneous speech (right)

3.2.3 Lip rounding

The effect of lip rounding on the glottal marking in word-initial vowels was also analysed. The mean data drawn from all speakers' results did not show any differences between the rounded and unrounded vowel groups in either of the speech styles (Figure 5.). In the read material, 55.3±7.1% of the unrounded vowels and 53.5±15.3% of the rounded ones showed glottal marking. In the spontaneous subcorpus these ratios were 33.2±10.3% and 33.6±7.7%, respectively. The intraspeaker differences were large in both speech styles. Some subjects used glottal marking more frequently in rounded, others in unrounded vowels, or the occurrence of glottal marking was similarly frequent in the two vowel classes. No tendency was found between the two speech styles: when a speaker glottally marked one kind of vowel (rounded vs. unrounded) more frequently in reading aloud, that did not mean that s/he glottally marked the same vowels more in his/her spontaneous speech as well. The results did not show any statistically significant difference (in general: $F(1, 3130) = 1.293$, $p = 0.256$, between the speech styles: $F(1, 3130) = 0.001$, $p = 0.971$).

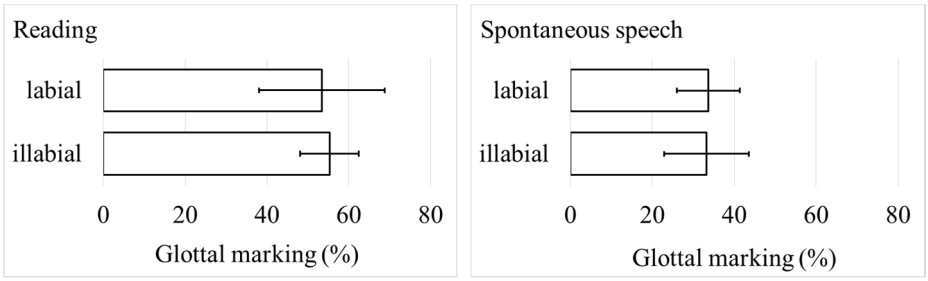

Figure 5.
Ratio of glottal marking in word-initial vowels
as a function of rounding
in reading aloud (left) and in spontaneous speech (right)

3.3 Temporal factors

3.3.1 Vowel duration

Our question about the relationship between vowel duration and glottal marking was whether the word-initial vowels that appeared with glottal marking were longer relative to the non-marked ones. As we hypothesized that slower articulation leads to higher frequency of glottal marking, here we did not separate the vowel qualities. The results are shown in Figure 6. In reading aloud, the glottally marked vowels' average duration was 83.9±10.6 ms, while the non-marked ones were shorter, 70.3±8.3 ms on average. In spontaneous speech, the mean duration of glottally marked vowels was 106.7±9.5 ms, while the non-marked ones were shorter again, with a mean of 80.7±7.0 ms. The general difference, namely glottally marked vowels being longer than non-marked ones,

was apparent in nine subjects' reading, and in the spontaneous speech of all the twelve participants. These differences were proven to be significant, suggesting that glottally marked vowels are longer than non-marked ones (in general: $F(1, 3144) = 54.524$, $p < 0.001$, between the speech styles: $F(2, 3144) = 6.404$, $p = 0.002$). Analysing the speech styles separately, we found that the difference in vowel duration was significant between the glottally marked and the non-marked vowels in both speech styles (reading aloud: Wilk's $\lambda = 0.415$, $F(2, 11) = 15.480$, $p = 0.002$; spontaneous speech: Wilk's $\lambda = 0.188$, $F(2, 11) = 47.363$, $p < 0.001$).

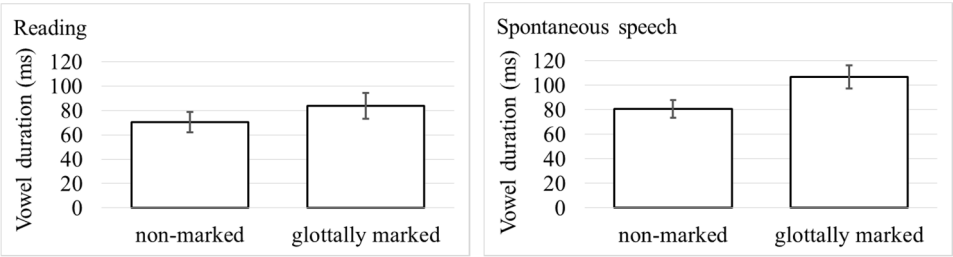

Figure 6.
Vowel duration as a function of glottal marking
in word-initial vowels
in reading aloud (left) and in spontaneous speech (right)

3.3.2 Articulatory rate

a) Absolute values of articulatory rate

Average articulatory rate. Our first question about the relationship between articulatory rate and glottal marking was if speakers with slower (average) articulatory rate produced more glottal marking in their word-initial vowels. The mean articulatory rate was 13.7 sounds/sec, and the standard deviation was 1.1 sounds/sec in both speech styles. Interspeaker variation was somewhat higher in spontaneous speech than in reading aloud, but still moderate. The subjects produced similar articulatory rates in the two speech styles; i.e., we were able to detect a strong correlation between the values in reading aloud and in spontaneous speech (Pearson's correlation: $r^2 = 0.801$, $p = 0.002$). As already described above in section 3.1, the appearance of glottal marking was 54.1±11.5% in reading aloud and 33.5±8.9% in spontaneous speech. As noted in section 3.1.1, this ratio also showed a certain correlation, i.e., the more frequently a speaker glottally marked their word-initial vowels in one speech style, the more they marked them in the other one as well (Pearson's correlation: $r^2 = 0.606$, $p = 0.037$). We hypothesized that a slower articulatory rate leads to a higher ratio of glottal marking in word-initial vowels. Based on the correlation data above, we might expect that the values of articulatory rate and frequency of

glottal marking measured subject-by-subject would also show correlation (Figure 7). In the read speech material, we found that the above mentioned tendency (that slower articulatory rate goes hand in hand with higher frequency of glottal marking) was present, however this correspondence still did not reach the level of significance ($r^2 = -0.574$, $p = 0.051$), which may imply that a larger corpus may prove this hypothesis. In any case, in our spontaneous subcorpus no significant relation was detected between the speakers' articulatory rate values and the appearance of glottal marking ($r^2 = -0.412$, $p = 0.183$).

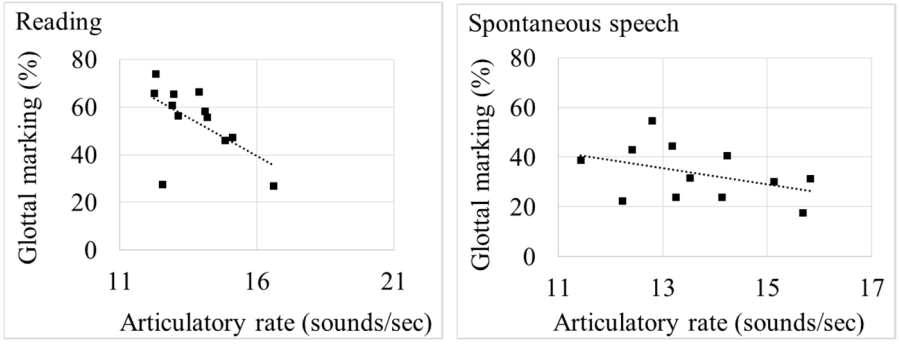

Figure 7.
Correlation of articulatory rate and ratio of glottal marking in word-initial vowels in reading aloud (left) and spontaneous speech (right)

Average articulatory rate as a function of voice quality. Our second question was whether the articulatory rate was slower in pause-to-pause intervals in which any glottal marking phenomenon appeared in the analysed vowels.

To answer this question, we compared the pause-to-pause intervals in which any of the word-initial vowels was pronounced with glottal marking and the ones in which there was at least one word starting with a vowel but none of them was glottally marked. In reading aloud, the mean of the articulatory rate was 13.9±1.0 sounds/sec in pause-to-pause intervals which did not show any word-initial vowel-related glottal marking, and 13.7±1.1 sounds/sec in those which contained at least one glottally marked word-initial vowel. In spontaneous speech, these results were 13.9±1.1 sounds/sec and 13.2±1.1 sounds/sec), respectively. Although the mean values apparently did not differ considerably, the statistical analysis revealed significant differences (in general: $F(1, 3144) = 121.231$, $p < 0.001$, between the speech styles: $F(2, 3144) = 48.240$, $p < 0.001$).

b) Slow vs. fast speech classification

After each pause-to pause interval with a word-initial vowel was detected and its articulatory rate was defined, the articulatory rate was categorized in two ways. The literature generally uses "slow" and "fast" speech categories in the presentation of results; therefore we also chose this classification as one method.

However, we also decided to perform a more detailed comparison, where "slow", "medium", and "fast" speech were considered. Thus we also applied a classification of the temporal data into three groups. The classifications were carried out by K-means cluster analysis in SPSS.

Twofold classification. The mean articulatory rate in the "fast" speech cluster was 15.2 sounds/sec in reading aloud and 15.0 sounds/sec in spontaneous speech, while "slow" tempo meant a mean of 12.5 sounds/sec in the first and 11.0 sounds/sec in the latter speech style. 54.0% of the word-initial vowels appeared in intervals considered as "slow" speech in reading aloud, while 36.9% of them in spontaneous speech. The glottal marking of word-initial vowels was more frequent in "slow" speech irrespective of speech style (Figure 8). In reading aloud, 59.4% of the word-initial vowels were glottally marked in "slow" speech, while 52.5% of them in "fast" speech. Interspeaker variability was higher in "fast" speech (SD = 18.3%, "slow" speech SD = 9.9%) in reading aloud. The difference between the two articulatory rates was larger with regard to the glottal marking of word-initial vowels in spontaneous speech (41.2% in "slow", and 30.9% in "fast" speech), and interspeaker variability was at 10.1% and 9.0%, respectively. The appearance of glottal marking was significantly different between the two temporal clusters when the two speech styles were considered together ($F(1, 3130) = 13.055$, $p < 0.002$). When reading aloud was analysed separately, "slow" and "fast" speech did not show any significant difference in terms of frequency of glottal marking (Wilk's $\lambda = 0.955$, $F(2, 11) = 0.517$, $p = 0.487$), while in spontaneous speech they did (Wilk's $\lambda = 0.467$, $F(2, 11) = 12.786$, $p = 0.004$).

Threefold classification. The mean articulatory rates in the three tempo clusters are presented in Table 1. The threefold temporal grouping revealed a significant effect of articulatory rate on the appearance of glottal marking in general ($F(2, 3130) = 5.627$, $p = 0.004$; between the speech styles: $F(2, 3130) = 6.308$, $p = 0.002$). In read speech, the frequency of word-initial vowel-related glottal marking did not vary with tempo changes (Figure 9), but was approximately 50% in all three clusters ("fast": 55.4%, "medium": 47.6%, "slow": 51.6%; Wilk's $\lambda = 0.882$, $F(2, 11) = 0.670$, $p = 0.533$). In addition, we observed that the slower the tempo, the higher interspeaker variability was (standard deviation: "fast": 9.2%, "medium": 10.2%, "slow": 20.0%). By contrast, spontaneous speech did show significant differences across the tempo clusters. In "medium" tempo, the ratio of glottally marked word-initial vowels was 24.2±9.3%, while in both the "fast" cluster and the "slow" one, a higher frequency of glottal marking was shown. The mean of the ratio of glottally marked word-initial vowels was 34.4±7.8% in "fast" tempo, and 50.8±18.1% in "slow" tempo, which was proven to be significantly different (Wilk's $\lambda = 0.300$, $F(2, 11) = 11.681$, $p = 0.002$). We tested the tempo clusters pairwise as well to see the differences in

detail. Wilcoxon-test was carried out and the *p*-value was expected to show significance below 0.01666 due to the threefold comparison. The "fast" cluster produced significantly less frequent glottal marking than the other two ones ("fast" vs. "slow": $Z = -2.667$, $p = 0.008$; "fast" vs. "medium": $Z = -2.824$, $p = 0.005$), while the "medium" and the "slow" tempi did not show any significant difference ($Z = -2.040$, $p = 0.041$).

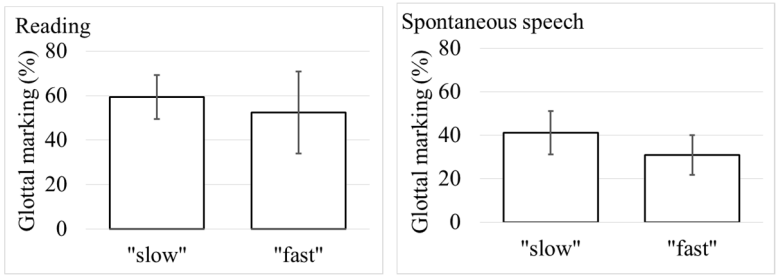

Figure 8.
Ratio of glottal marking in word-initial vowels as a function of articulatory rate clusters in reading aloud (left) and spontaneous speech (right)

Table 1. Mean articulatory rates in the three tempo clusters (sounds/sec)

	"slow"	**"medium"**	**"fast"**
reading aloud	10.6	13.3	16.6
spontaneous speech	9.0	13.1	15.6

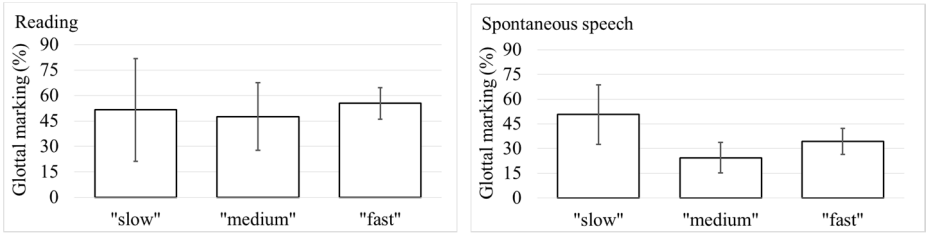

Figure 9.
Ratio of glottal marking in word-initial vowels as a function of temporal clusters in reading aloud (left) and spontaneous speech (right)

3.4 Word types

We compared the appearance of glottal marking in word-initial vowels between content and function words. We did not detect any differences between the two word types in either of the analysed speech styles. Some speakers tended to produce glottal marking more frequently in function words, some others in content words, and yet others produced glottal marking with the same frequency in both word types. In reading aloud, the frequency of glottal marking in the word-initial vowels of function words was 54.1±9.7%, and 54.4±12.3% in

content words; in spontaneous speech, the results were 33.8±8.9%, and 33.4±9.1%, respectively. The statistical analysis did not reveal any significant effect of word type on frequency of glottal marking ($F(1, 3130) = 0.401$, $p = 0.527$; between speech styles: $F(1, 3130) = 0.012$, $p = 0.912$).

4 Discussion and conclusions

The present study's aim was to analyse the glottal marking of word-initial vowels in two speech styles, reading aloud and spontaneous speech, based on 12 speakers' speech. In earlier studies of English, German and Polish, it was suggested that among several other factors, speech style, speech rate, vowel quality and word type had an effect on the glottal marking of word-initial vowels. In earlier studies, lower vowel height and slower articulation rate were found to enhance the likelihood of glottal marking, while speech style and word type had ambiguous effects (Rodgers, 1999; Malisz et al., 2013; Lancia & Grawunder, 2014). Our study raised the question if the phenomenon under study had similar facilitators in word-initial vowels in Hungarian.

In line with our first hypothesis (based on Rodgers' (1999) findings), speakers produced glottal marking significantly less frequently in spontaneous speech than in reading aloud. This difference might be traced back to the diverse speech planning strategies employed in reading aloud and spontaneous speech, which means among other things that prosodic marking is more direct in reading aloud due to a higher level of self-awareness in speech production.

The results of the German-Polish comparative study cited above (Malisz et al., 2013) showed that the glottal marking of word-initial vowels occurred more frequently in German than in Polish: 63.4% and 45%, respectively. In our material, we found glottal marking in 43.8% of word-initial vowels, which is close to the Polish data. In contrast with German and Polish, where glottal marking was more frequent in spontaneous speech (German: 72.5%, Polish: 53.5%) than in prepared speech (German: 59%, Polish: 41.5%), in Hungarian we found a higher ratio of glottal marking in read speech (54.1%) than in spontaneous speech (33.5%). Our results are in accordance with the assumption that read speech might be more clearly reflected by phonetic markers such as glottal marking.

We found (also similarly to earlier studies, e.g., Bőhm & Ujváry, 2008; Markó, 2013) that speakers producing more glottal marking in one of the speech styles also produced more glottal marking in the other style. This means that there was significant intraspeaker variation in the glottal marking of word-initial vowels between spontaneous speech and reading aloud, but the interspeaker differences did not correlate with speech style. Female speakers tend to produce more glottal marking in general – i.e., not only in word-initial vowels – in many

languages (e.g., in American English), also in Hungarian. This gender-specific difference was apparent in this specific phonetic position as well.

All the features of vowel quality were analysed, but only vowel height was found to play some minor role in glottal marking, backness and rounding did not at all. These latter effects were not analysed in the other languages in previous studies (to the authors' knowledge). In reading aloud, low and mid vowels were less frequently glottalized than high ones, while in spontaneous speech, high vowels were less frequently glottally marked than the other ones. The factor of vowel height played a significant role only in this latter speech style.

Slower articulation proved to enhance the possibility of glottal marking in word-initial vowels in our study as well, in accordance with our hypothesis. Both slower articulatory rate in the "carrier" pause-to-pause interval, and longer vowel duration went hand in hand with glottal marking. When dividing the articulatory rate into three clusters, we found that in the medium tempo word-initial glottal marking was less frequent. However, not only the "slow" but also the "fast" articulatory rate showed increased frequency of glottal marking in word-initial vowels.

In both German and Polish, the majority of prominent vowels are glottally marked. In the Hungarian corpus, utterance level prominence was not analysed due to its ambiguous phonetic characteristics. Even the literature on narrow focus, which is the most transparent phenomenon of prominence in Hungarian, has produced contradictory results (see Mády, 2012; Markó, 2012; Genzel et al., 2015; Szalontai et al., 2016; Mády et al., 2017), probably due to the syntactic determination of focus in Hungarian. The earlier studies which found phonetic correlates of focus prominence, found them in read speech, while the analysis of spontaneous speech did not reveal similar acoustic patterns. Moreover, in the read subcorpus of BEA, which was used for the present analysis, focus marking sentences were not included. Therefore, utterance level prominence could not be analysed unambiguously. Lexical level prominence, however, appears to be a more clearly definable phenomenon in Hungarian. Recently, several studies have proved that lexical prominence is expressed by durational differences (e.g., Szalontai et al., 2016; Mády et al., 2017; Markó et al., 2018b). At the lexical level, stress is highly predictable in Hungarian, assigned to the initial syllable of a content word. While content words bear first syllable stress, function words (e.g., definite and indefinite articles, postpositions, and conjunctions) appear as clitics, and do not bear stress. In contrast with many other languages, Hungarian is not assumed to display any covariance between word stress and vowel quality. Based on the distribution of lexical stress, we may assume that word types show interrelations with lexical prominence.

With respect to word type (content vs. function words), opposite tendencies were found in the languages mentioned above. In Polish, function words were

glottally marked in a higher ratio (50% compared to 37.7% of content words), whereas in German, content words showed a higher ratio of glottal marking (77.3% compared to 57% of function words). Pooled data (i.e., data not divided into read and spontaneous speech) for Hungarian showed the same ratios of glottal marking both in the case of content words (43.9%) and in function words (43.95%). As a function of speech type, we found that in reading aloud, the initial vowels of content words were also glottally marked at the same ratio as with function words: 54.4% and 54.1%, respectively. In spontaneous speech, the ratios were 33.4% for content words, and 33.8% for function words. These data imply that lexical prominence does not have an effect on the glottal marking of word-initial vowels in Hungarian. Or, as this factor was considered to raise an effect due to prosodic variation, there might be a difference with regard to this phenomenon in the languages. Another reason can also be assumed, similarly to Polish. Malisz et al. (2013) found a high number of phrase-initial function words in the Polish dialogue material, which is also the case in Hungarian (in both the read and the spontaneous subcorpora), due to the fact that the frequently used articles *(a, az, egy)* usually appeared in phrase-initial position. Therefore it can be supposed that phrase-initial position has a prevalent effect which overrides the effect of word type.

In our study, male and female speakers were involved in equal numbers, and the read material was the same in the case of all subjects. This contrasts with the German and Polish data, which represented different ratios of speakers in terms of gender (only males were involved in prepared speech, but both males and females in spontaneous speech), and the prepared material included various speeches. Although some of the effects have been found in all languages under analysis, the variability of the material and the relatively small number of the subjects might lead to ambiguous results. In several aspects (e.g., in the case of word type), language specific characteristics may be the reason behind the differences in the data. In order to support a better understanding of the universal and language specific elicitors of word-initial vowel-related glottal marking, future research will have to work with larger corpora which are also more amenable to crosslinguistic comparison.

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