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SYLWESTER JAWORSKI
MICHAŁ BARAN

ACOUSTIC FEATURES OF BURST RELEASE: A STUDY OF WELSH PLOSIVES

A b s t r a c t. The aim of this paper is to analyse the centre of gravity (COG) of release bursts in Welsh plosives in order to assess their importance in distinguishing between /p, t, k/ (here termed fortis) and /b, d, g/ (here termed lenis). The COG of a release burst appears to be particularly interesting as (i) it has not yet been studied extensively in the phonetic scientific literature on Welsh plosives (see for instance Ball, Ball and Williams, Jones, Morris and Hejná), and (ii) using the COG variable to distinguish between stops is not very common, as it is normally used to differentiate between places of articulation in fricatives. To achieve the aforementioned goals, the authors, inspired by a study of American English plosives conducted by Chodroff and Wilson, measured the COG of bursts in word-initial /p, b, t, d, k, g/.

Keywords: plosives; release burst; centre of gravity.

1. INTRODUCTION AND THEORETICAL BACKGROUND

While describing the sound inventory of any language, it is necessary to determine which articulatory and acoustic features are distinctive in that language. The repertoire of distinctive features encountered in the world's languages is really vast, but with respect to languages that contrast two series of plosives, the feature [Voice] typically differentiates the two series (Maddieson 28). In the phonetic literature, the distinctions voiced—voiceless

SYLWESTER JAWORSKI, PhD, Dr. Litt., University of Szczecin, Institute of Linguistics; e-mail: sylwester.jaworski@usz.edu.pl; ORCID: https://orcid.org/0000-0001-8851-3908.

MICHAŁ BARAN, PhD student at University of Szczecin, Institute of Linguistics; e-mail: michal.baran@usz.edu.pl; ORCID: https://orcid.org/0000-0002-7077-6424.

are often used interchangeably with fortis—lenis (Asmus and Grawunder; see also Ladefoged and Maddieson 95). Although fortis–lenis phonological contrasts can sometimes be defined in terms of a voiced–voiceless opposition, e.g. in Spanish or Polish, it should not be assumed that the rule holds for each and every language. It certainly does not in the case of Welsh, whose consonants are traditionally divided into the fortis and lenis series which cannot be accurately defined by referring to the feature [Voice], as word-final /b/ and /d/ remain distinct from their voiceless counterparts /p/ and /t/ despite being devoiced, e.g. *brat* 'rag' vs. *brad* 'treachery', *cip* 'glimpse' vs. *cib* 'husk' (Asmus and Grawunder). The conclusion that emerges from Asmus and Grawunder's research is that fortis–lenis distinctions are both multifaceted and, most likely, language-specific.[1] Since voicing does not suffice to define the contrast, there must be another acoustic property, or a combination of properties, that differentiate the /p, t, k/ and /b, d, g/ series of Welsh plosives.

There have been a number of studies on Welsh plosives that have touched upon, or focused exclusively on, the organisation of the Welsh laryngeal system. Ball, in his account, links certain articulatory aspects with various approaches to laryngeal system distinction. According to him, the voiceless--voiced distinction reflects the state of the glottis during the closure stage, the aspirated-unaspirated distinction refers to the state of the glottis during and after the release of the closure, and the fortis–lenis distinction is related to the force of articulation. Ball's analysis of Welsh plosives reveals that voicing is not distinctive in the initial position but may sometimes be distinctive in the final position for /b, d, g/. He also states that other factors such as VOT/aspiration, together with preceding vowel length and quality, offers considerably more reliable marking of the two-consonant series under review. Jones notices that the unaspirated plosives are not constantly voiced and that VOT is decisive in distinguishing between the fortis and lenis series. Similarly to Ball, he acknowledges the potential influence of the force of articulation, but claims that there is no experimental justification. In a monograph on Welsh phonetics, Ball and Williams present analogous observations, i.e. they notice that /p, t, k/ are aspirated and voiceless, while /b, d, g/ are unaspirated and frequently devoiced, depending on position. Moreover, they claim that unreleased plosives are less frequent in Welsh than in English. Morris and Hejná focus on pre-aspiration and report that, in Bethesda Welsh, both fortis

[1] Irrespective of the articulatory and acoustic features used to define the fortis–lenis distinction, the former term always implies greater articulatory energy expenditure than the latter (Ladefoged and Maddieson 95).

and lenis plosives may be pre-aspirated, but it is the fortis series that is more likely to exhibit this feature. Iosad in his analysis of Welsh provection employs the fortis–lenis distinction and the "laryngeal realism" approach which identifies Welsh as an "aspiration" language. Moreover, he summarises previous research on Welsh consonants in order to show that the fortis–lenis distinction is supported by both phonetic and phonological observations. All of the aforementioned papers seem to present the same account as far as two key facts are concerned, i.e. that the Welsh language features the fortis–lenis distinction of consonants in which the fortis /p, t, k/ are aspirated and voiceless, and the lenis /b, d, g/ are unaspirated and their voicing varies from partial to non-existent.

As regards the articulation of plosives, three stages of production must be distinguished: the closing stage, the hold stage and the release stage (Davenport and Hannahs 20). The closing stage refers to the moment when the active articulator approaches and comes into contact with the passive articulator. It is followed by the hold stage, which begins as soon as the active and passive articulators form a complete closure. The duration of the hold phase may prove useful, for instance, in distinguishing between the series of sounds within the laryngeal system. It is claimed that, in citation forms or after a pause, /p, t, k/ tend to have a longer hold phase than /b, d, g/. The differences, however, are not evident in connected speech (Ogden 98).

Once a complete closure is made, the air pushed out of the lungs accumulates in the oral cavity behind the closure and, consequently, the intraoral pressure builds up. When the constriction is removed, usually by lowering the active articulator, the release stage begins. The release stage may, but does not have to, involve aspiration, i.e. an audible puff of air resulting from an egressive pulmonic airstream passing through an open glottis[2] (Davenport and Hannahs 22; Bickford and Floyd 23; Ladefoged and Maddieson 66; Trask 36; Stevens 451). The amount of aspiration following the release of a plosive is usually described in terms of voiced onset time (VOT), defined as "the length of time after the release of a stop closure before the start of modal voicing for the following sound" (Ladefoged and Maddieson 66). With respect to VOT, the world's languages make use of three possibilities; namely, voiced (negative VOT), voiceless unaspirated (VOT equals zero or is very short) and voiceless aspirated (long positive VOT) (Ladefoged and Maddieson 45). In English, for instance, the phonological status of aspiration is debatable. Aspiration is the

[2] The feature of aspiration, also referred to as spread glottis, is shared by aspirated plosives and voiceless sonorants (Ladefoged and Maddieson 69).

primary acoustic feature that distinguishes the voiceless plosives /p, t, k/ from their voiced counterparts /b, d, g/, but only at the beginning of a syllable before a stressed vowel (Wells 44). It is due to its occurring in a predictable context that aspiration is not considered to be a phonological feature of English (e.g. Hyman; Cruttenden; Davenport and Hannahs 23). However, it is also argued that aspiration is not totally predictable, as word-initial /b, d, g/ can be phonetically voiceless, but unaspirated. Thus, what distinguishes word-initial /b, d, g/ from /p, t, k/ is the presence/absence of aspiration (Lisker).

In the Welsh language, aspiration is not distinctive either, due to all plosives being aspirated in most phonological contexts, albeit to different extents (Asmus et al., "Fortis-Lenis or Voiced-Voiceless"). However, in languages which maintain a three-way phonological contrast, aspiration can be used as one of the distinctive features. This type of contrast exists in the Thai language, which distinguishes between voiced, voiceless unaspirated and voiceless aspirated stops (Ladefoged and Maddieson 56; Davenport and Hannahs 114).

Yet another articulatory feature of plosives is the presence of a release burst, defined as "a small audible explosion which accompanies the release of a plosive," frequently manifested in a spectrogram as a sudden peak of energy (Trask 61). As noted above, a release burst constitutes an important part of stop articulation, and its phonetic qualities have been attracting researchers' attention for decades. In one of the first such studies, Halle, Hughes and Radley suggested that the acoustic features of a release burst are related to stop voicing, in that voiced stops feature a prominent low-frequency component in the burst spectrum. Similar research was conducted, for instance, by Zue on American English stop consonants, revealing that the coronal /t/ had a higher spectral peak than /d/, while the differences in dorsal or labial stops were not recorded. The studies mentioned above had serious drawbacks though, as they were based on a statistically inadequate number of speakers and they overlooked the influence of phonetic voicing being present during the hold phase or release burst. This gap in the literature was filled by several studies which statistically confirmed most of the aforementioned observations for certain varieties of English (Sundara; Kirkham; Chodroff and Wilson, "Burst Spectrum"), but also for other languages such as Dutch (van Alphen and Smits), German (Harrington) and Georgian (Vicenik).

The present study has been inspired by the paper by Chodroff and Wilson ("Burst Spectrum"), which examines the influence of various qualities of the stop burst in the pronunciation of American English stops. In the production study, they measured the COG of the release bursts, together with three higher spectral moments, i.e. standard deviation, skewness and kurtosis. The analysis was based on recordings of 18 speakers who read sentences formed by inserting CVC syllables resulting from crossing the stop consonants with the vowels of English into a carrier phrase. Altogether, the authors examined 5,047 tokens. It was confirmed on the basis of both laboratory and corpus studies that the initial burst spectrum may serve as a secondary cue to voicing, with the difference being clearly visible for labial and coronal stops, but not fully conclusive for the dorsal.

The primary objective of this paper is to determine whether or not the acoustic properties of the release burst following the Welsh plosives constitute a phonetic feature that underlies the distinction between /p, t, k/ and /b, d, g/. This goal is achieved by comparing the mean values of the COG of the release bursts occurring after the Welsh /p, b, t, d, k, g/ produced in word initial position. Secondary objectives include: (i) searching for potential differences in COG values resulting from the place of articulation and their influence on the laryngeal system marking, and (ii) determining whether or not there is an interplay between COG values and aspiration. In order to achieve the latter goal, the COG measurements are confronted with the results of the previous studies by the authors on the importance of aspiration in distinguishing between /p, t, k/ and /b, d, g/ in Welsh.

2. THE STUDY

This investigation seeks to determine whether or not the COG values of the release bursts occurring after the Welsh /p, b, t, d, k, g/ contribute to distinguishing between the fortis and lenis series. The value of COG, defined as the average frequency present in the fricative spectrum, is correlated with, and dependent on, the place of articulation of the fricative (Ladefoged and Maddieson; Chodroff and Wilson, "Acoustic–Phonetic and Auditory Mechanisms"). Since a release burst consists of friction noise, the COG values of release bursts are also expected to be related to the place of articulation of plosives. An additional purpose of this study is to establish whether the COG values of the release bursts of the aspirated lenis and fortis plosives of the Welsh language form a consistent pattern, similar to that described in Chodroff and Wilson ("Acoustic–Phonetic and Auditory Mechanisms").

2.1 Methodology and participants

The acoustic analysis performed for the purposes of the study included samples of read speech obtained from 6 female native speakers, aged 39–73, from Aberystwyth, who use their language at home and at work. The plosive sounds examined were found in the onset of monosyllabic native lexemes currently in use. The lexemes were taken from previous corpora (Asmus and Grawunder) but were further amended by adding more lexemes to obtain the required number of tokens for measurements. As far as the syllable structure of the lexemes is concerned, there were instances of the following: CVC e.g. *beth* 'what', CCVC e.g. *blas* 'taste', CV e.g. *tŷ* 'house' and CVCC e.g. *gynt* 'formerly'. The CCVC were, however, excluded from the COG analysis. The list of the tokens may be found in the appendix.[3] The target words were placed in the carrier phrase *Dw i heb ddweud X ond Y!* 'I didn't say X but Y!' and were ordered in such a way that every lexeme appears in the recording twice in a strong (Y) and twice in a weak (X) prosodic position. For each Welsh plosive occurring in onset position, the COG values of 20 tokens per speaker were measured. Thus, the results presented in section 3 are based on 720 measurements of bursts (10 tokens x 6 speakers x 6 plosives x 2 positions). Selected native lexemes were also recorded in ordinary short sentences as distractors. If a speaker mispronounced the target word, they were asked to repeat the sentence. The recordings were made in July 2017 in Aberystwyth (Wales). During the sessions, the informants sat at a table with a Sinn7 mPod USB Studio microphone, connected to a Macbook Air laptop (late 2017), placed approximately twenty centimetres from the speakers. Praat software was used to make the recordings, digitise the data, and determine the COG value of each plosive (Boersma and Weenink). As suggested by the authors of Praat, the original sampling rate was set at 44,110 Hz.

Following Chodroff and Wilson ("Burst Spectrum"), the burst onset was identified from a visual examination of the waveform and spectrogram as a sudden rise in sound energy occurring at the release of a plosive. By contrast, the burst offset was either marked by the onset of the following vowel or, particularly in the case of the fortis plosives /p t k/, by a sudden drop in sound energy, followed by a period of glottal friction representing aspiration, as illustrated in figure 1. In the upper panel, the voiceless stop /k/ occurs in initial position in the word *col* 'bosom', while in the other panel, the same plosive constitutes the final sound on the word *trec* 'gear'. The two bursts differ not

[3] The authors are aware of the varying conventions of the Welsh orthography. The spelling in the word list comes from the Geiriadur Prifysgol Cymru (Thomas et al.).

only with respect to duration, but also intensity, correlated with the amplitude of friction. The burst of the initial velar plosive is almost twice as long as that of the final bilabial, 16 ms and 9 ms respectively. As for their intensity, the amplitude of changes in air pressure visible in the waveform provides evidence that the initial burst was produced with a greater amount of articulatory effort than the final one. As noted above, the acoustic properties of bursts may play a role in distinguishing between fortis and lenis plosives.

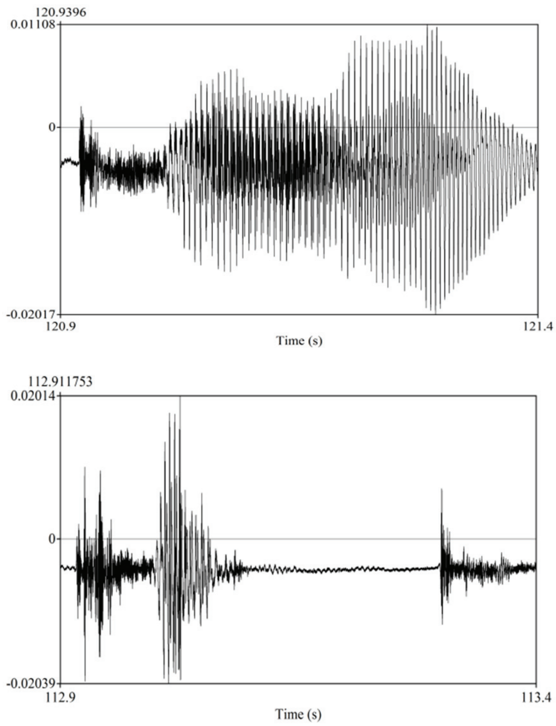

Figure 1. Initial and final bursts following the Welsh /k/ produced in *col* ‘bosom’ and *trec* ‘gear’.

In order to make the methodology consistent with other studies of plosives (e.g. Chodroff and Wilson, “Burst Spectrum;” Sundara), the recordings were resampled at 16 kHz, pre-emphasised above 1,000 Hz, and high-pass filtered at 200 Hz. The duration of the analysis Hamming window was set at 3 ms. As noted above, the COG parameter can be thought of as a frequency which divides the spectrum into two halves (Ladefoged and Maddieson; Stevens; Chodroff and Wilson, “Burst Spectrum,” “Acoustic–Phonetic and Auditory Mechanisms”). The amount of energy in the top half, i.e. the higher frequencies, is equal to that in the bottom half, i.e. the lower frequencies. Thus, sounds with a lot of high-frequency energy, such as [s] or [z], will have a higher centre of gravity than ones with low-frequency energy, e.g. [x] or [ɣ].

In addition to the COG, the three higher spectral moments, namely, standard deviation, skewness and kurtosis, were calculated. In terms of this study, these three parameters describe the extent to which the distribution of frequencies differs from the normal, bell-shaped curve. Standard deviation, alternatively referred to as dispersion, specifies the range of frequencies within which the energy of a sound is concentrated. Low values of this measure indicate that the frequencies are close to the COG, while high values mean that the energy is dispersed over a large frequency range. Skewness describes numerically whether or not the distribution of frequencies on both sides of the COG is symmetrical. A curve may be skewed either to the right or the left. In the case of a negative skew, more scores are to the left of the COG, while a positively skewed curve has more scores to the right of the COG. Finally, kurtosis is a measure of how much the shape of the spectrum around the centre of gravity is different from the mathematically defined normal curve in terms of steepness or shallowness. A positive kurtosis value means that the curve is steep, while a negative value indicates that the curve is flat (Howitt and Cramer; Boersma and Weenink).

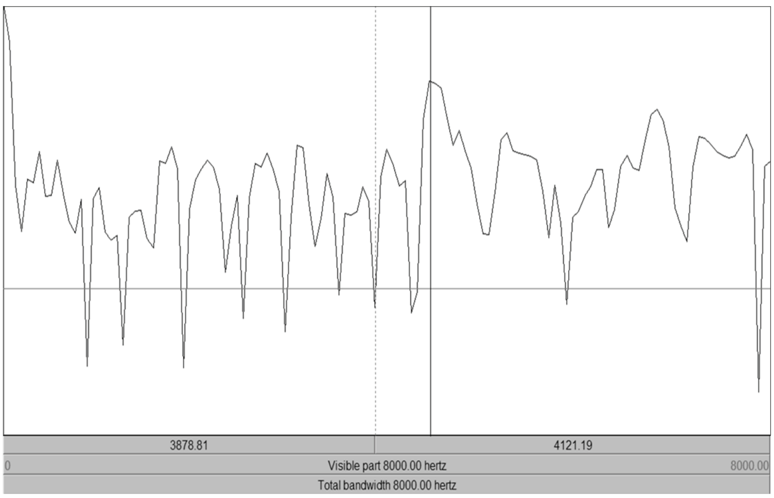

Figure 2. Burst spectrum of a word-initial Welsh /d/.

While calculating the values of the three spectral moments, we followed Chodroff and Wilson ("Burst Spectrum"). By way of illustration, figure 2 presents a spectrum of the burst release of a word-initial Welsh /d/. This token has a peak frequency of 4,450 Hz (marked by the black line), but its COG (dotted line) is 3,878 Hz. The standard deviation of this sound is very large (2,559 Hz), which suggests that the energy is distributed over a large range of frequencies. As for the skewness, it has a negative value of –0.15. This parameter specifies that the left wing of the distribution is longer than the other one. Finally, the kurtosis value (–1.27) suggests that, in this particular case, the distribution of frequencies varies quite significantly from the Gaussian curve and confirms that the distribution of frequencies is quite flat, as shown in figure 2.

3. RESULTS

An acoustic analysis of the plosives examined revealed that the alveolars /t/ and /d/ have, on average, the highest COG values, while the mean COG values of the bilabials /p/ and /b/ are found at the other end of the scale. As shown in figure 3 below, the median values, represented by a horizontal line within each box, form the same pattern as their means presented in table 1.[4] The six boxplots also differ, to a relatively small extent, with respect to the range of frequencies within which the release bursts are realised. The ranges, delimited by the whiskers, do not appear to be correlated with the place of articulation of a plosive.

It is worth pointing out that the results presented in this work reflect those obtained by Chodroff and Wilson ("Burst Spectrum") with respect to the relationship between the COG values of the voiced-voiceless of AmE and lenis-fortis plosives of Welsh. Although /p/ and /t/ have a higher COG than /b/ and /d/ in both languages, the relationship is the reverse in the case of the velar plosives. In fact, in our study, the differences between the mean COG of the bursts following /k/ and /g/ turned out to be minimal, which was also confirmed by a statistical test that yielded an insignificant result ($F = 0.98$, $df = 1$, $p = 0.3242$).[5] As for the other places of articulation, the COG difference

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[4] The median denotes or relates to a value or quantity lying at the midpoint of a frequency distribution of observed values or quantities, such that there is an equal probability of falling above or below it (Howitt and Cramer).

[5] In Chodroff and Wilson's "Burst Spectrum," the voiced AmE /g/ also had a slightly higher COG than its voiceless counterpart when they analysed speech samples recorded in a laboratory setting. The connected speech data produced a more consistent pattern, in that the voiceless plosives had higher COGs than the voiced ones.

is much more profound between the alveolars (F = 382, df = 1, $p < .00001$) than between the bilabials (F = 4.92, df = 1, p = 0.0274).

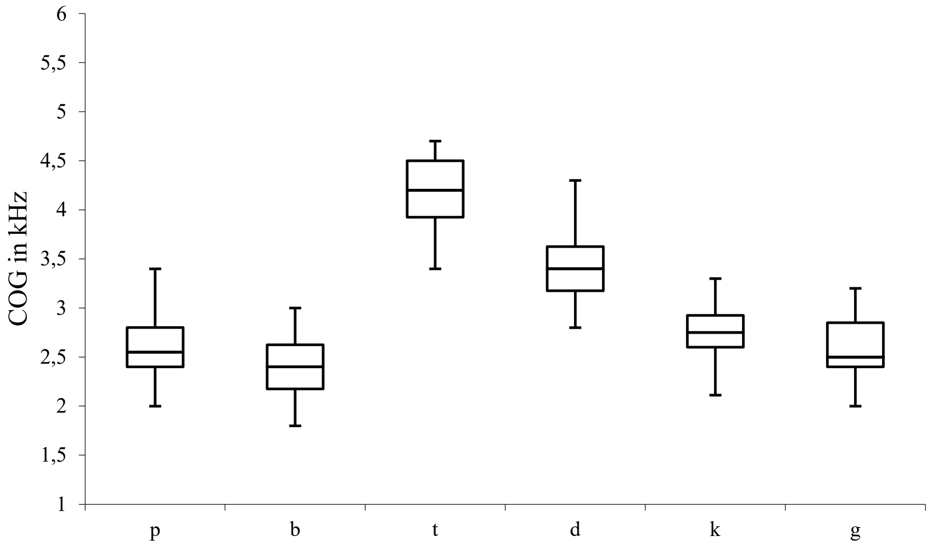

Figure 3. Boxplots showing the COG values of the release burst of the Welsh plosives.

With respect to standard deviation, the results obtained indicate that the acoustic energy is dispersed over a relatively large range of frequencies. On the whole, the range of frequencies may be said to be approximately half of the COG frequency (see table 1). However, the alveolar plosives differ in this respect from the bilabials and velars in that there is a noticeably greater difference between /t/ and /d/. As a matter of fact, a comparison of the standard deviations of /t/ and /d/ reached the level of statistical significance (p = 0.0338), while it did not in the case of the bilabials and velars ($p > .05$).

The COG values produced by the participants vary to a certain extent. A statistical analysis of the data, performed by means of a one-way analysis of variance,[6] yielded an insignificant result for /p/ (F = 2.16, df = 5, p = 0.064), /b/ (F = 2.12, df = 5, p = 0.067) and /t/ (F = 2.21, df = 5, p = 0.058).[7] On the other hand, the same test revealed that there exists a significant statistical

[6] This type of analysis, also referred to as one-way ANOVA, is frequently used to compare two or more groups in terms of their mean scores on a dependent variable (Howitt and Cramer 187).

[7] Even though the results did not reach the 5 per cent threshold of statistical significance, they are very close to it. Thus, they should be verified by further studies.

inter-speaker difference between the COG values obtained for the plosives /d/ ($F = 4.59$, $df = 5$, $p = 0.0007$), /k/ ($F = 3.85$, $df = 5$, $p = 0.0029$) and /g/ ($F = 4.95$, $df = 5$, $p = 0.0004$). Thus, the results of the statistical tests seem to correlate positively with the size of range of frequencies within which a release burst occurs. As shown in figure 3 above, the frequency ranges of /d/, /p/ and /k/, marked by the whiskers, are somewhat greater than those of the other plosives.

The skewness values presented in table 1 also strongly suggest that the alveolars /t/ and /d/ differ from the other plosives as their skewness is negative, which means that the left wing of the distribution of frequencies below the COG is longer than the right wing. The data also show that the distribution is skewed leftwards to a much greater extent in the case of the fortis plosive than the lenis one. The other plosives, i.e. the bilabials and velars, are skewed to the right. Since the mean values of skewness fall within the (–1, 1) range, the data are normally distributed (Howitt and Cramer).

		COG		Standard deviation		Skewness		Kurtosis	
		Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Bilabial	/p/	2591	350	976	221	0.71	0.31	–0.54	0.38
	/b/	2373	337	904	238	0.89	0.42	–0.46	0.72
Alveolar	/t/	4159	412	1882	189	–0.76	0.43	–0.81	0.63
	/d/	3374	349	1578	233	–0.51	0.42	–0.87	0.64
Velar	/k/	2755	282	873	175	0.69	0.38	–0.53	0.58
	/g/	2565	319	802	194	0.58	0.45	–0.50	0.44

Table 1. Spectral moments for word-initial stop consonants of Welsh. COG, spectral and standard deviation given in Hz and other spectral moments as unitless.

As for kurtosis, the data indicate that the distributions of frequencies differ to a certain extent from the Gaussian curve, yet they still represent natural distribution patterns. The negative values of kurtosis reported in table 1 also point to the conclusion that all the curves are relatively flat (Howitt and Cramer 33).

4. DISCUSSION

COG differences may be regarded as one of several factors that contribute to the fortis–lenis distinction of Welsh plosives, but they cannot be considered to be the only criterion that defines the divide. This is because the differences between the COG values recorded for the pairs of homorganic plosives under review vary from substantial, as in /t/ and /d/, to inconclusive, as in the case of /p/ and /b/, and /k/ and /g/. In this regard, our results are not fully consistent with other studies investigating the acoustic features of release bursts of plosives in other languages with respect to the COG values of the velar plosives (e.g. Sundara; Vicenik; Chodroff and Wilson, "Burst Spectrum").

It has been suggested that the fortis–lenis dichotomy in Welsh is a function of the aspiration–voicing combination, so these two correlates should also be taken into consideration (Ball; Asmus et al., "Fortis-Lenis vs Voiced-Voiceless Plosives"; Asmus and Grawunder; Baran). Based on the results reported by the authors in other papers (see, for example, Asmus et al. "Fortis-Lenis or Voiced-Voiceless"; Asmus et al., "Fortis-Lenis vs Voiced-Voiceless Plosives"), it appears that, in monosyllabic words, Welsh plosives may be not only released, but also aspirated in both initial and final position. This observation is partially confirmed by other studies of Welsh plosives. For instance, Ball and Williams claim that the lenis plosives may show little aspiration in initial position. With respect to word-final position, one of the most influential phonetic studies on the acoustic correlates of the fortis–lenis distinction in Welsh conducted by Ball does not report the length of word-final aspiration as this feature was not measured, so it is impossible to confront the authors' finding with this paper. The issue of word-final release bursts is not addressed in this paper, as it is restricted to plosives occurring in word-initial position due to the fact that contrasts of any kind are particularly likely to manifest themselves in prosodically strong positions. Therefore, a follow-up study should be devoted to the potential differences between the values of the above-mentioned parameters in initial and final position.

It is difficult to conclusively determine the influence of aspiration on the COG of the burst on the basis of this study. As noted by Chodroff and Wilson ("Burst Spectrum" 2767), aspiration has an effect on the COG of a burst as the "degree of aspiration and concentration of burst energy have a common articulatory origin." Therefore, if the burst section of a spectrum includes aspiration, its COG is likely to be lowered in the case of /t/ and /d/ and, probably, for the other plosives. However, the effect of aspiration cannot be ruled out of hand since all plosive realisations in this study were aspirated, yet separating the burst from glottal friction may sometimes be problematic. The fact that all Welsh plosives in the contexts under review are, to some extent, aspirated may also influence the aforementioned inconclusiveness of the COG measurements in distinguishing between the fortis and lenis sounds. In

Chodroff and Wilson's study, the contrast between aspirated and unaspirated sounds was clearly reflected in the COG values. The presence of aspiration in both the fortis and lenis plosives of the Welsh language seems to reduce the differences in COG values, rendering them inconclusive.

It has also been suggested that the vowel following a plosive has a significant effect on the acoustic characteristics of the burst. Chodroff and Wilson ("Burst Spectrum") provide compelling evidence that, in American English, the COG of a plosive reaches the highest values when followed by the high front vowel /iː/, while the following mid back /ɔː/ noticeably lowers the COG. This effect must be associated with the different internal configurations of the speech organs that produce various plosive-vowel sequences. If the high front /iː/ follows a plosive, the front part of the dorsum is already raised towards the palate when the plosive is released and, consequently, the airstream passes through a very narrow channel, which results in additional turbulence that is superimposed on the burst. The amount of friction produced by the airstream passing through the opening between the palate and the back part of the tongue in the case of /ɔː/ is much weaker and, therefore, its effect is negligible. Needless to say, the results of the current study would probably be more accurate if the following vowel had been taken as a variable in the current study.

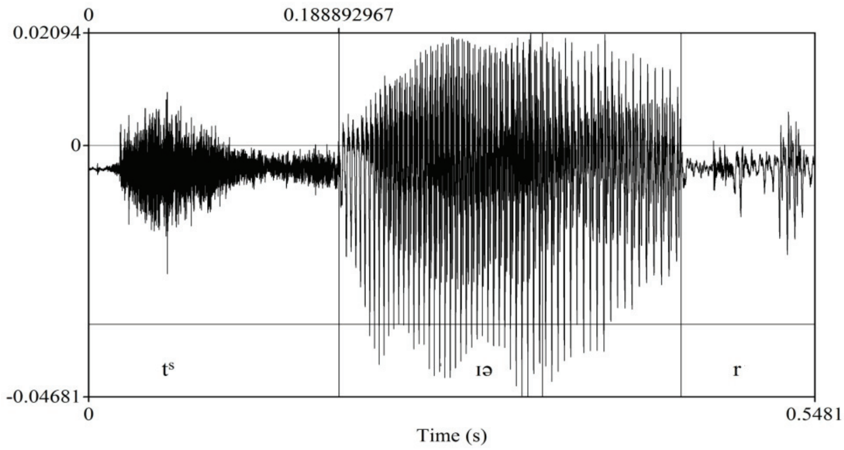

Figure 4. An affricated Welsh /t/ pronounced in the word *tŵr* 'tower'.

The acoustic analysis of the recordings also revealed that the Welsh alveolar plosives exhibit a strong tendency towards affrication (Trask 14). The release of an affricated plosive differs considerably from that of an aspirated one, in that there is no distinct burst. Instead, the release marks the onset of a period of strong friction whose intensity steadily increases and, having reached a peak, it gradually drops as the plosive is released into the following vowel. The affricated allophone of the Welsh /t/, pronounced in the word *tŵr* 'tower', is depicted in figure 4. This token is phonetically an affricate sound due to it being made up of a complete closure followed by an 83-millisecond period of friction. Since affrication is a lenition process resulting from reduction of articulatory effort, it may affect the plosive sounds in any language. It is possible that the affrication of Welsh plosives is influenced by an analogous process occurring in English (Cruttenden 151).

To sum up, the COG variable cannot be regarded as the only factor distinguishing between the lenis and fortis plosives in Welsh, as the differences between the two series are not consistent and vary depending on the place of articulation. Furthermore, it is difficult to draw conclusions on the COG-aspiration interplay in Welsh, as all plosives are aspirated. Finally, our analysis has also revealed that the noticeable tendency towards affrication exhibited by Welsh plosives should be further examined in a follow-up study.

5. CONCLUSIONS

This study aimed at determining whether or not the centre of gravity of a burst release can be used as an acoustic parameter to distinguish between the fortis and lenis plosives of the Welsh language. Since COG turned out to be a significant factor in distinguishing between the two series of English plosives (see Chodroff and Wilson, "Burst Spectrum") of which only the voiceless ones are aspirated, we assumed that the Welsh plosives may differ in this respect as both the lenis and fortis series are aspirated. The extent to which they are aspirated might be reflected in the values of COG.

The centre of gravity, as well as standard deviation, skewness and kurtosis, turned out to be of limited value as far as defining the lenis–fortis distinction of the Welsh plosives is concerned. The results obtained of standard deviation show that, in the case of the Welsh plosives, the acoustic energy of the burst is dispersed over a relatively large range of frequencies. The skewness values suggest that the alveolars /t, d/ differ from the other plosives with respect to the distribution of frequencies. To be more precise, /t, d/ are skewed negatively, whereas the other plosives are skewed positively. Finally, the kurtosis data indicate that the distributions of frequencies significantly differ from the Gaussian curve, yet their values represent natural distribution patterns.

As is usually the case, the results presented in this paper address one issue, but at the same time they raise a number of interesting questions. To begin with, a follow-up study should definitely take into account the potential influence the following vowel may have on the acoustic properties of the release burst of a plosive, as suggested by Chodroff and Wilson ("Burst Spectrum"). It would also be worth establishing the extent to which the acoustic properties of the release burst are correlated with the position occupied by a plosive within the word. The waveform in figure 1 above suggests that word-final bursts tend to be produced with less articulatory effort. Therefore, their characteristics are likely to differ significantly from those occurring in prosodically strong positions. This seems to be of particular significance for the Welsh language, in which, as the data obtained by the authors suggests, word-final plosives in monosyllables are not only released, but they also seem to have a certain amount of aspiration. Apart from measuring their COG values, it would also be interesting to find out whether they form the same pattern as in initial position. Another study could examine the acoustic properties of release bursts in non-aspirating languages, e.g. Polish or Russian, where the distinction between voiced and voiceless plosives hinges exclusively on the voicing feature. Last but not least, an investigation of the COG values of lenis and fortis fricatives of Welsh should be undertaken, as it might throw more light on the acoustic characteristics of the sounds.

Yet another investigation that might shed some light on the acoustic properties of the Welsh plosives would involve an analysis of the affrication phenomenon. Although the current study shows that /t, d/ are particularly prone to affrication, other plosives may be susceptible to this process as well.

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Appendix 1

Target words used for the analysis of the release burst of initial plosives

beth	deng	pell
both	dod	pen
budd	dos	peth
bys	dŵr	prep
byth	dydd	pwy
car	gan	tad
côl	gên	teg
côr	ger	tŵr
cudd	gynt	trec
cwch	gyr	tŷ

CECHY AKUSTYCZNE ŚRODKA CIĘŻKOŚCI PLOZJI: STUDIUM WALIJSKICH SPÓŁGŁOSEK ZWARTO-WYBUCHOWYCH

Streszczenie

Celem niniejszego artykułu jest przeanalizowanie środka ciężkości plozji walijskich spółgłosek zwarto- wybuchowych co pozwoliłoby ocenić znaczenie tego czynnika w rozróżnianiu między /p, t, k/ (w artykule określane jako mocno artykułowane – fortis) a /b, d, g/ (w artykule określane jako słabo artykułowane – lenis). Środek ciężkości plozji wydaje się szczególnie interesujący ponieważ: (i) nie był jeszcze dogłębnie analizowany w badaniach fonetycznych walijskich spółgłosek zwarto-wybuchowych (por. Ball 1984; Ball i Williams 2011; Jones 1984; Morris i Hejná 2019) oraz (ii) używanie środka ciężkości plozji jako czynnika różnicującego między spółgłoskami zwarto-wybuchowymi jest dosyć rzadkie, jako że tego czynnika używa się zwykle do różnicowania między spółgłoskami szczelinowymi o różnych miejscach artykulacji. Aby osiągnąć wspomniane wcześniej cele, autorzy artykułu, zainspirowani badaniem spółgłosek zwarto-wybuchowych amerykańskiej odmiany języka angielskiego przeprowadzonym przez duet Chodroff i Wilson (2014), zmierzyli środek ciężkości plozji w nagłosie dla /p, b, t, d, k, g/.

Słowa kluczowe: spółgłoski zwarto-wybuchowe; plozja; środek ciężkości.