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RELEASE BURST IN POLISH HOMORGANIC STOP GEMINATES

The paper endeavours to verify a commonly accepted observation that Polish homorganic stop geminates are unreleased. Fifteen Polish subjects participated in the experiment, producing stop geminates in different contexts specified for the place of articulation, articulatory tempo, and voiced-voiceless distinction. The collected samples were acoustically analysed for presence or absence of the release burst. The results do not corroborate a putative unreleased status of Polish homorganic stop geminates. They show, however, that the frequency of released geminates strongly depends on the place of articulation, with dental /t, d/ released most frequently. Voiceless stops tend to be more readily released than voiced stops, though this tendency is only close to significant. Moreover, a significant impact of the tempo of articulation on the occurrence of the release burst has been demonstrated for both voiced and voiceless stops – longer utterances are conducive to unreleased realisations of geminates.

The present study came into being with the aim to specify and refine the knowledge about the release burst in Polish stop geminates with the same place of articulation. Present understanding of the problem is far from precise and the number of studies dealing with phonetic realisation of stop geminates in Polish is but meagre compared to a widespread interest that stop geminates have received in English.

Polish stop geminates are either underlying, e.g. *le**kk**o*, *mo**tt**o*, or derived through gemination across morpheme boundaries, e.g. *po**d d**rzewem*, *ja**k k**iedyś*. Wierzchowska (1980), and Dukiewicz and Sawicka (1995) observe that when two stop consonants with the same place of articulation occur together, the first may be optionally unreleased. Little is known, however, about the nature of their putative 'optional' status. In other words, there has been no empirical data on the factors that may influence their realisation as unreleased. Similarly, Jassem (1974) notes that a stop is usually unreleased when followed by a stop with the same place of occlusion whereas Kopczyński (1977) writes that Polish stops are

unreleased before homorganic stops without any comment on conditioning factors. Both 'optionally unreleased' and 'usually unreleased' lack descriptive power about the extent to which Polish releases its homorganic stop clusters. Indeed, it has been the author's observation, as a teacher of English phonetics, that Poles have problems with controlling the release burst in homorganic stop geminates in English, which are always unreleased (Jones 1956, Abercrombie 1967, Ladefoged 1975, Jun 1995, Gimson 2001).

Unreleased stops-articulatory and acoustic consequences

Generally, the release burst is interpreted as the breaking of contact between two articulators, which results in the release of overpressure built up behind the occlusion (e.g. MacKay 1978). Such an interpretation, which is definitely true for stops with the homorganic place of articulation, does not hold for two stops with different places of articulation. Whereas in one-place stop clusters the contact between two articulators is not disrupted, in sequences of two nonhomorganic stops, the closure of the first stop must be released; otherwise, the second stop would be produced with an incorrect or dual place of articulation (Henderson and Repp 1982). For reasons of terminological consistency, Repp (1981) proposed the interpretation of the release burst both in acoustic terms – as the portion of the speech signal with acoustic consequences – as well as articulatory gestures that might be involved. A complete classification of the release burst must therefore contain the following aspects (after Henderson and Repp 1982):

1. *Unreleased*: The occlusion is maintained as in a stop preceding a homorganic stop or in many utterance-final stops without the release burst
2. *Silently released*: No release burst in the acoustic record
3. *Inaudibly released*: Visible release burst in records of the signal but not readily detectable by ear
4. *Weakly released*: Release burst detectable by ear but clearly weaker than in class 5
5. *Strongly released*: Release burst is followed by substantial aspiration or voicing

For the purpose of the present study, only categories (1), (4), and (5) are of relevance, for (2) and (3) solely refer to nonhomorganic stop clusters. The homorganic geminate can be either released, when articulators part resulting in a brief acoustic transient (Fant 1973, Dorman et al. 1977) or distinct spikes of a few milliseconds duration (Henderson and Repp 1982), or they can be unreleased, which results in a double-duration silent compression phase. Categories (2) and (3) bear on sequences of two stops with different places of articulation where re-positioning of articulators may have no acoustic consequences (2) or may have no auditory relevance (3).

Unreleased stops – auditory consequences

Even though the release burst is not phonemically distinctive in any of the world's languages (Tsukada et al. 2004), different studies have demonstrated that release bursts provide very salient place information (Malecot 1958, Winitz et al. 1972, Blumstein and Stevens 1980) and voiced-voiceless information (Malecot 1958, Wolf 1978). Fujimura and colleagues (1978) showed that pre-vocalic stop transitions are perceptually stronger than post-vocalic stop transitions, which means that the release burst is auditorily a more salient cue to the recognition of a stop than its closing movement. This led Ohala (1990) to hypothesise about phonological assimilation processes affecting clusters of two stops. For example, in a VCCV sequence, the first stop consonant often lacks a release burst and, accordingly, it is perceptually weaker than the neighbouring released stop. The second stop, however, has both burst and transition cues to its place of articulation, thereby obtaining a perceptual advantage over the preceding stop. Extrapolating from this evidence, Ohala (1990) suggested that the combined strength of place cues for the second stop might be able to overwhelm the corresponding place cues for the first stop, and thus result in a listener perceiving the entire consonant sequence as one homorganic stop cluster with the place of articulation of the second consonant. Ohala (1990) claims that such unintentional misperceptions might be responsible for a widely attested cross-linguistic phenomenon of phonological place assimilation in consonant sequences.

An acoustic and temporal consequence of the lack of the release burst in stop clusters is a period of silence[1]. A spectrographic analysis reveals that a closure period for each stop results in momentary acoustic silence – for voiced occlusion, spectrograms display low frequency murmur in fundamental frequency indicative of vocal cord pulsing (Halle et al. 1957). In the case of a cluster of two stops, the first of which is unreleased, the total closure period is about twice as long as that for a single intervocalic stop (Westbury 1977 reported in Repp and Williams 1985, Repp 1982) and, consequently, "there is no acoustic or perceptual basis for subdividing the total closure interval into portions pertaining to the two consecutive (perhaps overlapping) stop closures" (Repp and Williams 1985: 445). In fact, several studies have demonstrated that silence, and not only the release burst, can provide a sufficient condition for the perception of stop manner. Bastian et al. (1961, reported in Raphael and Dorman 1980) showed that the insertion of a sufficiently long interval of silence after /s/ in a naturally produced word *sore* causes listeners to hear *store*. In a same vein, Summerfield and Bailey (1977) inserted silence between the friction and steady-state vowel formants of synthetic /si/ and /su/, which resulted in the listeners' recognition of the syllables as /ski/ and /spu/

[1] In English, in a corpus of 144 utterances, a mean closure duration of VCV ranged from 40 ms to 74 ms whereas, in a VCCV context, the overall duration of two stops, the first of which was unreleased, reached 127 ms (Raphael and Dorman 1980: 270).

respectively. In a study which assessed the interval of silence necessary to report two homorganic stops, Pickett and Decker (1960) manipulated silence duration between the two syllables in the word *topic* and found that when the closure interval in *topic* was lengthened to approximately 250 ms, listeners reported hearing *top pick*. Similarly, Repp (1976) has demonstrated that for voiced stops the closure duration needed approximately 200 ms to be recognised as a sequence of two homorganic stops. Interestingly enough, Raphael and Dorman (1980) provided evidence that the closure interval between two stops with the same place of articulation is of the same duration as the closure interval between two stops with different places of articulation. In a corpus of 60 utterances of 15 speakers, spectrographic analysis revealed that the average closure intervals in *I paid Bailey* and in *I paid gaily* did not differ from that of *I paid Daley*. The average intervals were in fact identical, revolving around 106 ms (Raphael and Dorman 1980: 273).

Experiment

Material

In order to fulfil the requirements of a comprehensive analysis for presence or absence of the release burst in Polish geminates, we set three variables as analytical criteria:

1. occlusion place – the relationship between the place of articulation – bilabial /pp, bb/, dental /tt, dd/, velar /kk, gg/[2] – and releasing or unreleasing the first stop in a sequence.
2. voiced-voiceless compression – the influence of the voiced compression in sequences /bb/, /dd/, /gg/ and voiceless compression in /pp/, /tt/, /kk/ on releasing or unreleasing the first stop in a sequence.
3. articulatory tempo – the influence of a speech tempo on releasing or unreleasing the first stop in a sequence.

Accordingly, we created the following 6 carrier two-word phrases and 6 carrier sentences to provide material for the analysis specified for the aforementioned variables:

1. zła**p p**iłkę
2. ko**t t**ańczył
3. ja**k k**iedyś
4. lu**b b**ardziej
5. po**d d**rzewem

[2] Due to the fact that Polish is recognised for devoicing obstruents word-finally and before a voiceless consonant, we did not include combinations of voiced followed by voiceless stops. For the sake of analytical symmetry, neither did we consider sequences of voiceless followed by voiced stops.

6. wyści**g g**ęsi
7. najpierw zła**p p**iłkę, a później podaj
8. patrzyli, jak ko**t t**ańczył na środku pokoju
9. mimo lat, wyglądała ślicznie, ja**k k**iedyś dawno temu
10. każdy jest mniej lu**b b**ardziej zadowolony z życia
11. usiedli po**d d**rzewem, by trochę odpocząć
12. zafascynowani, patrzyli na wyści**g g**ęsi wzdłuż rzeki

The above phrases and sentences fulfil all the three variables put forward as the analytical criteria, i.e. sequences of all the places of articulation, combinations of both voiced and voiceless occlusions, and tempo of articulation.

Subjects

15 subjects, monolingual native speakers of Polish, participated in the experiment. All subjects were volunteers and were not paid for their participation. None of the subjects had any speech or hearing disorders, nor any indication of such.

Procedure

All the subjects were asked to read 12 carrier phrases and sentences. For the first 6 phrases, the subjects were not instructed as to the manner and tempo of articulation. However, for the sentences, the speakers were encouraged to use their natural, conversational tempo. Recordings were made in a quiet room, using a microphone of 100Hz-16kHz frequency sensitivity range, posited 15 centimetres from a speaker's mouth. The recordings were sampled at 16000 Hz and stored in a computer disc in a wav. format for further analysis.

Next, we used Praat software package 4.4.33 (Boersma 2001) to obtain waveforms and spectrographic displays of all digitalised samples. In each stop sequence, we were looking for any signs of parting of the articulators between the first and the following stop, resulting in a brief acoustic transient (Fant 1973, Dorman et al. 1977), or distinct spikes of a few milliseconds duration (Henderson and Repp 1982). When there were no acoustic manifestations of the release burst, the sequence was classified as unreleased. On the other hand, when a spectrogram revealed acoustic rupture in the occlusion between two stops, the sequence was classified as released[3]. Figure 1 shows the unreleased sequence in the phrase *zła**p p**iłkę*. Figure 2 demonstrates the release burst in the same phrase.

[3] We found instances of releases visible only in spectrograms which, however, gave no auditory impressions – the same problems are reported in Henderson and Repp (1982). In the present analysis we applied acoustic rather than auditory criteria, hence such sequences were labelled as released.

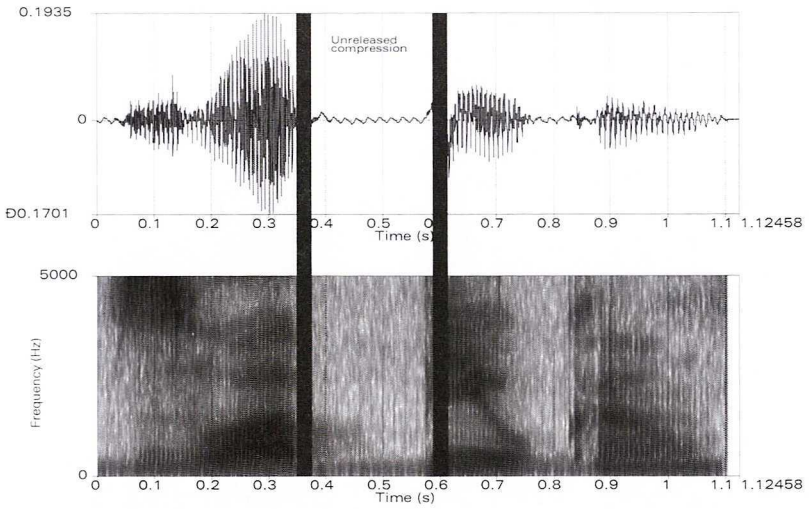


Fig. 1. Waveform and spectrogram of an unreleased sequence /pp/ in *zła**p p**iłkę*

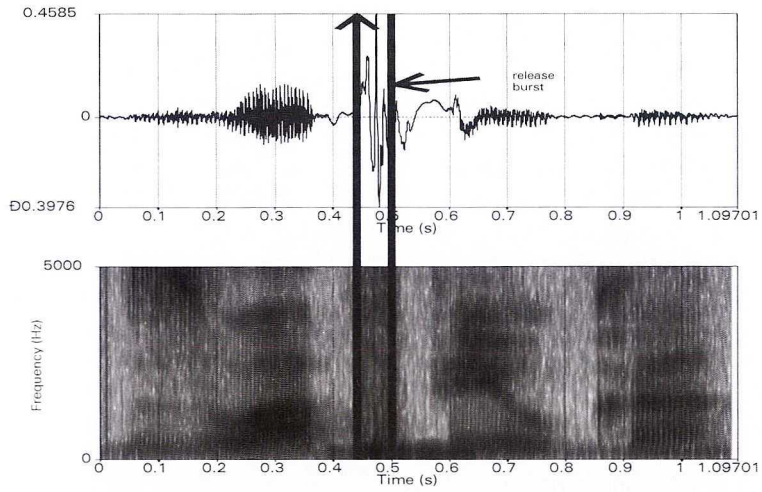
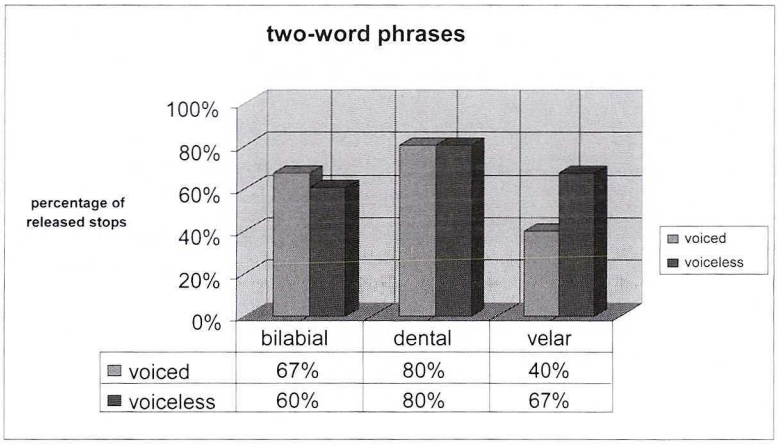


Fig. 2. Waveform and spectrogram of a released sequence /pp/ in *zła**p p**iłkę*

Results

Table 1 presents the percentage of released geminates in two-word carrier phrases.

Table 1. Percentage of released geminates in two-word carrier phrases



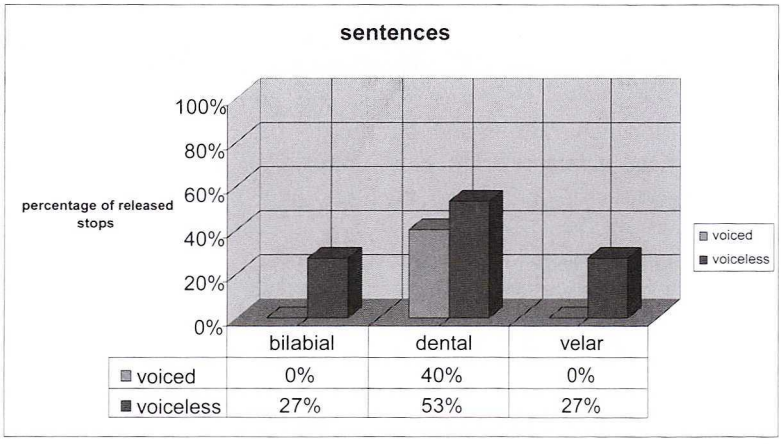
	bilabial	dental	velar
voiced	67%	80%	40%
voiceless	60%	80%	67%

The results show a high percentage of released sequences, with /t, d/ amounting up to 80% irrespective of voicing. 60% and 67% of the subjects released /p/ and /b/ respectively. The smallest percentage of releases was observed for /g/, however its voiceless counterpart /k/ was released 67% of the time.

We ran a Cochran Q test to verify the significance of the influence of the place of articulation on the release burst. For voiced occlusion, the correlation between the place and the release obtained very high significance ($p=0.009^{**}$). At the same time, for voiceless occlusion, the correlation between the place and the release was not significant ($p=0.173$). Additionally, a *Chi*-square test revealed that the voicing contrast was not a factor in the presence or absence of the release burst ($p>0.05$).

Table 2 presents the percentage of released geminates in carrier sentences.

Table 2. Percentage of released geminates in carrier sentences



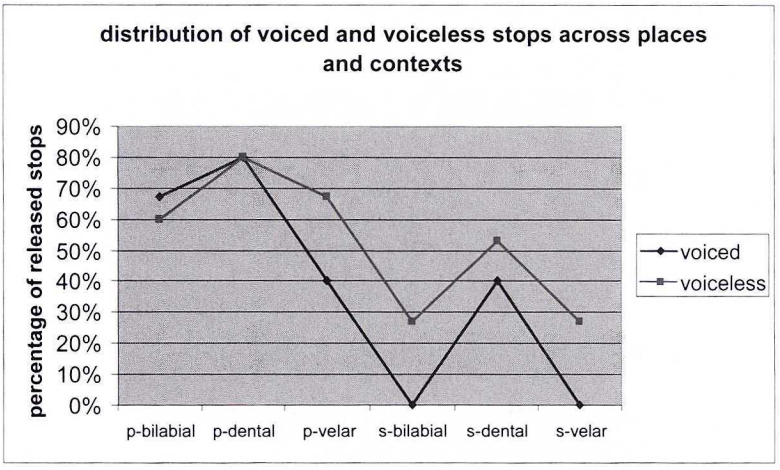
	bilabial	dental	velar
voiced	0%	40%	0%
voiceless	27%	53%	27%

The results reveal a considerable impact of speech tempo on releasing stop geminates by Poles. As in the case of two-word carrier phrases, again /t/ and /d/ are characterised by the highest percentage of releases – 53% and 40% respectively. None of the subjects released voiced /b/ or /g/ and only 27% of all /p/ and /k/ tokens had the release burst.

We administered a Cochran Q test to seek statistical significance between the place of articulation and the release burst. Similarly to the two-word context, high significance was obtained for the voiced occlusion (p=0.002**) but was not found for the voiceless occlusion (p=0.169). The *Chi*-square test revealed a statistically significant relationship between the voiced occlusion and the absence of the release burst (p=0.014*).

Table 3 demonstrates the distribution of released geminates across two-word carrier phrases and sentences.

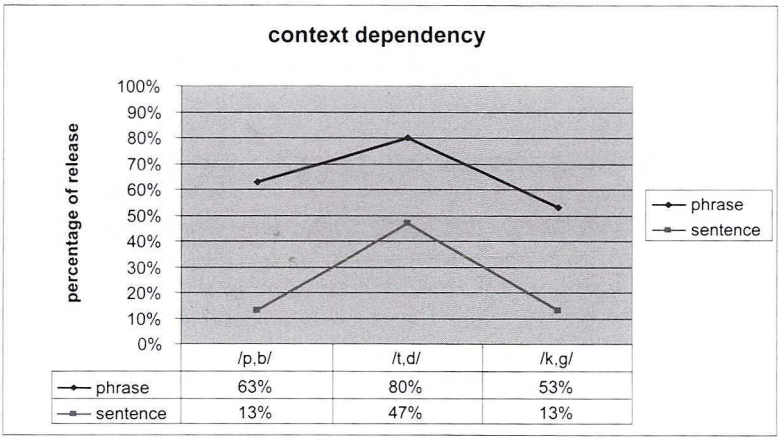
Table 3. Distribution of voiced and voiceless released geminates across the places of articulation and the contexts



The data in Table 3 clearly show that voicing of geminates decreases the number of released stops. The tendency is evenly correlated in sentences, which suggests that, with increasing speech tempo, the subjects tend to reduce the release rate in voiced geminates. The data obtained for the two-word phrases are much less consistent – /t/ and /d/ have equally high percentage of releases and /p/ and /b/ differ only by 7%.

Finally, we administered two global *Chi*-square tests to seek significance for the influence of speech tempo and the voiced-voiceless occlusion on the release rate. The speech tempo (two-word phrases versus sentences) does have an impact on releasing stops. Faster tempo reduces the number of released stops with very high significance (p<0.001**) (see Table 4).

Table 4. Percentage of released geminates in two-word phrases and sentences



	/p,b/	/t,d/	/k,g/
phrase	63%	80%	53%
sentence	13%	47%	13%

The impact of voicing on the release rate was found nearly statistically significant, however a null hypothesis could not be rejected ($p=0.051$). Voiceless geminates tend to be released to a greater extent than voiced geminates irrespective of speech tempo. Still, however, more research is needed to give more confidence in this observation.

Discussion

In the present study, we have found evidence to question a generally accepted claim that Polish homorganic stop geminates are unreleased. Quite to the contrary, the data we obtained show a high release rate, especially in isolated two-word phrases. We have no knowledge of any empirical studies in Polish phonetics that have generated a common belief in an unreleased status of Polish stop clusters with the same place of articulation. Consequently, we are not in a position to ascribe the obtained data, which are in clash with what is commonly accepted, to the differences in methodology applied in our study and previous studies on the subject. We hypothesise, however, that observations which led to the assumption that Polish homorganic stop geminates are unreleased were based on the production of longer sentences and an analysis of natural conversations. Nevertheless, as already mentioned, we do not know what type of an empirical approach was assumed in the previous studies – be it an instrumental acoustic analysis or sheer auditory observations. How important a selected methodology is for further conclusions may be best demonstrated by the two contexts chosen for the present study. Two-word phrases displayed a high rate of released stops but it does not necessarily imply that Polish stops are invariably released in stop geminates. What it means is that it is natural for them to be released when the context is limited and the principles of maximising distinctiveness are at play (Flemming 2002 for a dis-

cussion). When posited in longer sentences, the rate of released stops drastically decreases not only due to contextual cues which reduce the contrastive burden of phonetic distinctions, but also due to a well documented effect of the tempo of articulation on production (Munhall et al. 1992, Cummins 1999, Waniek-Klimczak 2005).

The place of articulation has a very strong effect on whether the first stop in a sequence will be released or not, irrespective of the tempo of articulation (Table 4). Dentals have the highest rate of releases whereas the two peripheral places are characterised by lower release rates. Further empirical research is needed, however, to provide rationale for the observed tendency. What we can do for now is only conjecture about possible factors contributing to more released dentals as compared to velars and bilabials. Dental stops are articulatorily located between peripheral velar and bilabial stops, which results in their lower acoustic distinctiveness. Moreover, a lack of the release burst will necessarily impair the perception of the place of articulation in stops (Malecot 1958, Winitz et al. 1972, Blumstein and Stevens 1980). The speakers participating in the experiment appear to have consistently more often released dentals, aiming at increasing their distinctiveness. This strategy seems not to have been necessary for velars and bilabials, owing to their peripheral place of articulation and thus sufficient distinctiveness. As stressed before though, no unassailable explanation of this tendency is affordable without further relevant, methodologically precise, auditory experiments.

Even though an effect of the voiced-voiceless occlusion on the release rate did not obtain statistical significance, the data plotted in Table 3 show a fairly regular distribution pattern across the places and contexts. Although in the case of the two-word phrases no relationship can be noted, the geminates in the sentences are characterised by consistency in the precedence of voiceless over voiced released stops. The subjects seem to have been less willing to release stops if the whole cluster had voicing in closure. This observation would have interesting theoretical consequences had it only been also confirmed in the two-word phrases, which unfortunately was not the case. If there are further experiments in the future that will attest a similar tendency to release voiceless more than voiced geminates, it may mean that voicing has an inhibitory effect on the release rate in Polish homorganic stop geminates.

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