Intraoral Pressure Variation In Nasal–Plosive And Plosive–Plosive Sequences In German

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Abstract

In an attempt to examine the nature of the non-pulmonic airstream fuelling the releases of nasals and plosives observed in a variety of stop–stop sequences in German, intraoral pressure changes in sequences of labial stop + dorsal stop in symmetrical and asymmetrical vowel contexts are examined. While the pressure changes in plosive-plosive sequences concur with the findings of previous studies, nasal–plosive sequences exhibit a good deal of intra- and interspeaker variability, showing that here too, the possibility of both egressively as well as ingressively fuelled stop release.

1 Introduction

Following on from other studies into epiphenomenal non-pulmonic sound production [3, 6, 4, 5], Simpson [8] examined the auditory and acoustic correlates of epiphenomenal non-pulmonic sound production in German, showing how a velaric airstream seems to be driving many of the releases of nasal and oral stops in stop–stop sequences when the place of articulation of the first stop is anterior to that of the first, e.g. [-mn-], [-mk-], [-pk-]. By contrast to true clicks, the velaric airstream is not caused by an active movement of the tongue to bring about rarefaction of the air in the lingual cavity formed between the dorso-velar and labial/alveolar closure, but rather by regular articulatory movements of the lips, jaw and tongue during double closure.

One aspect of the description which remained unexplained in Simpson's description was that the release of nasal in such a sequence is generally click-like, being fuelled by an ingressive velaric airstream, whereas the burst of the first plosive in a plosive–plosive sequence was regularly found to be fuelled by egressive airflow. This paper offers an explanation of the differences in terms of the changes in air pressure which occur *before* the coarticulatory double closure is made.

Fig. 1 shows schematic representations of articulator position and air pressure at three stages in (a-c) the plosive–plosive sequence [pk] and (d-f) the nasal–plosive sequence [mk]. In (a) air pressure ca. 30 ms after closure for [p] approximates subglottal pressure. In (b), the second, dorso-velar closure is made with pressure still above atmospheric in the lingual cavity. Prior to release of the first, bilabial closure in (c) the articulators are moving away from each other, slightly reducing the pressure in the lingual cavity (smaller +). By contrast, in (d–f) the nasal–plosive sequence, pressure in the lingual cavity following the dorso-velar closure in (d) still approximates atmospheric pressure, and it is only articulatory movement during the double closure which brings about, in (f), rarefaction of the air in the lingual cavity.

Due to the range of temporal possibilities available to the the speaker to synchronise the movements of tongue, lips, jaw and velum with phonation, as well as the differences in tongue movement during the double closure, arising from different vowel qualities flanking the consonant sequence, it soon becomes apparent that we should find a large range of changes in intraoral air pressure in such nasal–plosive, plosive–plosive sequences.

This study examines the variation in intraoral pressure in six German speakers producing different stop–stop sequences as they occur in authentic German words and phrases. These are preferred to more easily controllable nonsense sequences as we would ultimately like to interpret our results in relation to different degrees of cohesion correlating with different linguistic structures.

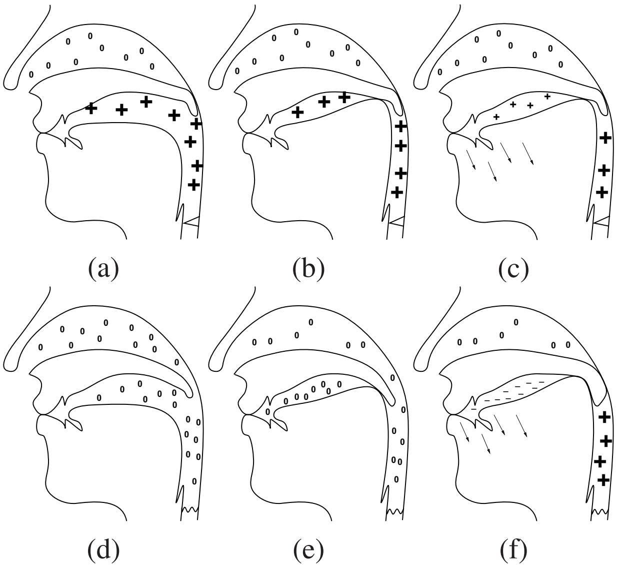

Figure 1: Schematic representation of three stages in the production of (a-c) the plosive–plosive sequence [pk] and (d-f) the nasal–plosive sequence [mk]. **0** = approx. atmospheric pressure; **+ / +** = above atmospheric pressure; **–** = below atmospheric. Arrows indicate movement of articulators towards bilabial release. See text for details of each stage.

2 Data and method

Intraoral pressure changes were registered using the *PCquirer*™ package from Scicon R&D Inc. A short length of flexible tubing approximately 4 mm in diameter was attached to an upper or lower incisor. This was done using a length of waxed dental floss tied around a tooth and subsequently around the end of the tubing (fig. 2a). The other end of the tube was inserted into a length of slightly larger diameter tubing which in turn was attached to the hand-held transducer interface (fig. 2b).

(a) (b)

Figure 2: (a) Attachment of tube to lower incisor, and (b) to hand-held transducer interface.

Six female speakers of Standard German with certain regional characteristics took part in the experiment. Table 1 contains the 17 short sentences that were used to elicit nasal–plosive and plosive–plosive sequences in the context of close and open vowels. Each sentence was written on a card and the stimulus order was randomised. Since the software capture time is limited to five seconds, subjects were instructed to repeat the sentence on a card at a natural rate until capture had finished. This ensured two to three complete tokens of each sentence in each five-second window. The sentence list was read twice by all the speakers using normal phonation as well as twice by one of the speakers using whisper (not further discussed here). Tokens of initial dorsal plosives were also elicited with preceding vowel or fricative in order to estimate stop duration when not in overlap and therefore concealed by a preceding oral or nasal stop.

Table 1: Stimulus sentences containing plosive–plosive and nasal–plosive sequences in different close and open vowel contexts.

01 Wir sind ab Kiel gefahren.	10 Sie wurden im Kartenhaus gesehen.
02 Wir sind ab Karlsruhe gefahren.	11 Sie wurden im Kino gesehen.
03 Es blieb kaum jemand stehen.	12 Wir sind nach Kiel gefahren.
04 Er blieb ganz ruhig.	13 Wir sind nach Karlsruhe gefahren.
05 Ich habe dich richtig liebgewonnen.	14 Er war ganz ruhig.
06 Der Zug ist später abgefahren.	15 Es fiel kaum jemand auf.
07 Danach gab es Lebkuchen.	16 Wir sind ab Gießen gefahren.
08 Wir sind am Kartenhaus vorbeigefahren.	17 Wir sind ab Garmisch gefahren.
09 Wir sind am Kino vorbeigefahren.	

Finally, audio and pressure files were converted from the PCquirer format to wav format for subsequent analysis.

3 Results

Fig. 3 shows pressure plots and spectrograms of (a–b) plosive–plosive and (c–d) nasal–plosive sequences in different pre- and post-vocalic contexts. The vertical arrows are aligned in each case with the burst of the first stop as identified from the spectrogram. Despite expected disruption of bilabial articulation due to the presence of the tube attached to the teeth just behind the lips, the first plosive is acoustically present in the majority of cases, sharing the same auditory and acoustic features of a velarically fuelled stop release reported previously [8], i.e. acoustically weak, often inaudible and generally lasting no longer than 30 ms.

The intraoral pressure plots concur with our expectations, based on the hypothetical considerations laid out in the introduction, as well as with the findings of previous studies [6, 1, 2]. In fig. 3a intrao-

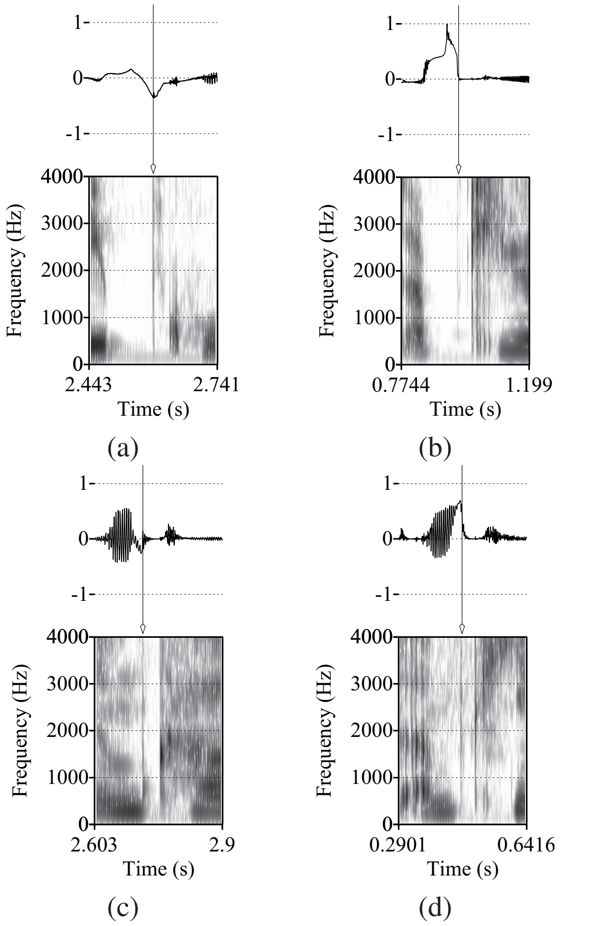

Figure 3: intraoral pressure plots and spectrograms of the stop-sequences from tokens of (a) [-pk-] in "Lebkuchen" (speaker: BR), (b) [-pk-] in "ab Kiel" (speaker: MK), (c) [-mk-] in "im Kartenhaus" (speaker: JH) and (d) [-mk-] in "am Kino" (speaker: JH). Arrows are aligned with the burst of the first stop as visible in the spectrogram.

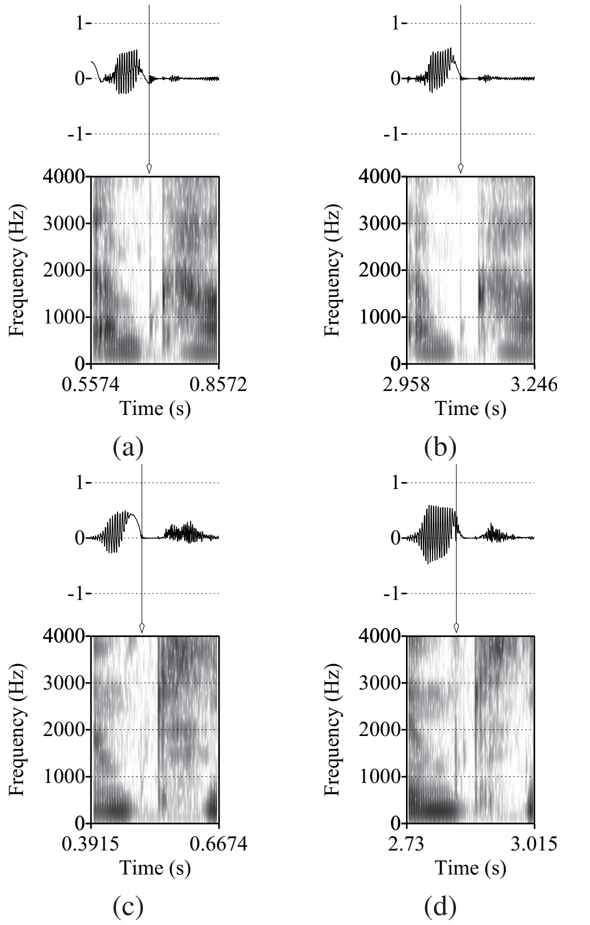

Figure 4: Intraoral pressure plots and spectrograms of the [-mk-] sequences from tokens of (a–b) "am Kartenhaus" and (c–d) "im Kino". All tokens are produced by the same speaker JH. Arrows are aligned with the burst of the first stop as visible in the spectrogram.

ral pressure rises following closure of the bilabial stop, only to drop sharply prior to release suggesting a backward movement of the tongue from the front [eː] to the back [uː] once the velar closure had been made. By contrast, in fig. 3b, intraoral pressure begins to rise following bilabial closure and rises again more sharply prior to release of the bilabial plosive, suggesting that the intraoral cavity created by the labial-dorsal closure is being reduced in size by the movement towards the front vowel stricture for [iː] in "Kiel". The nasal–plosive token shown in fig. 3c also concurs with our hypothetical considerations. If we assume that closure for the dorsal plosive overlaps the closure of the bilabial nasal, then the drop in intraoral pressure prior to release of bilabial closure is brought about by a downward movement of the tongue from the the half-close vocalic stricture in "im" to the more open stricture in "Kart(enhaus)". However, in a number of other nasal–plosive sequences we find an increase in oral pressure which begins with the onset of the oral closure for the nasal and which continues up to the release of labial closure. An open vocalic stricture precedes the nasal–plosive sequence in fig. 3d and the half-close vowel of "Kino" follows, so that the increase in intraoral pressure could be attributed to the lingual movement during the double closure. However, the magnitude of the pressure increase shown in fig. 3d is larger than the negative excursion in fig. 3c, by the same speaker (JH), which leads us to suspect that another factor might be involved. This is supported by the pressure plots of nasal–plosive sequences in symmetrical vowel contexts shown in fig. 4. Analogous to the fig. 3d, intraoral pressure begins to increase with the onset of bilabial closure in the nasal and in most cases continues to remain above atmospheric up to the release of bilabial closure. An increase of intraoral pressure during bilabial nasals in general can be ruled out. None of the speakers exhibited any noticeable positive or negative change in intraoral pressure during bilabial nasals in an intervocalic environment ("Garmisch"). What seems more likely is that velic closure required for the necessary build up of pressure in the oral plosive begins quite early in the nasal, producing at some something which could be described as an epenthetic [b] or [g͡b]. What is of most interest here, however, is that contrary to prior speculation, based on acoustic data and auditory impression alone [7, 8], it would seem that the velaric airstream fuelling the burst of nasals in such sequences is not exclusively ingressive, but egressive as well. Indeed, as we would expect, there is a good deal of intra- and interspeaker variation.

Figure 5: intraoral pressure plots of the [-mk-] sequences from tokens of "am Kartenhaus" from speaker HO (a–b) and SN (c–d).

Fig. 5 shows the pressure plots in the nasal–plosive sequences from four tokens of "am Kartenhaus" from two other speakers HO (a–b) and SN (c–d), in both cases taken from the same recording. Spectrograms have been excluded to save space. Whereas intraoral pressure in HO's first token remains positive throughout (5a), the second shows a negative excursion prior to release. In SN's two tokens, consistent with all the others produced, there is only a slight, if any, increase in pressure following bilabial closure, but always a significant drop in pressure prior to bilabial release.

4 Discussion

This study of the intraoral pressure in labial-dorsal stop sequences throws some light on the complexity and variation involved in their articulatory synchronisation. In particular, the nasal–plosive sequences involve changes in labial, lingual, velic and glottal activity, which does not occur simultaneously. Perhaps the most important finding of this study is the positive intraoral pressure found in many nasal–plosive sequences, implying an egressive fuelled release in many cases. Given this, it is interesting to speculate again on differences observed in the nature of releases found in nasal–stop sequences, e.g. [-nk-] ("in Kiel") as opposed to a stop–stop sequence [-tk-] ("geht gut") [8]. If both are velarically fuelled, and may in many cases both be egressive, any difference must be caused by the dynamics of the release itself, giving rise to a 'clean', unfricated release of the nasal as opposed to a slower, fricated release in the plosive.

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