The Relationship between Intraoral Air Pressure and Tongue/Palate Contact during the Articulation of Norwegian /t/ and /d/

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Abstract

Our paper addresses the question of covariation between intraoral air pressure and size of contact area between tongue and palate during the articulation of the Norwegian stop consonants /t/ and /d/. An EPG investigation of the two plosives shows a larger contact area between tongue and palate for /t/ than for /d/. An investigation of intraoral air pressure during the articulation of the two plosives shows higher air pressure for /t/ than for /d/. We suggest that the covariation between intraoral air pressure and contact area between tongue and palate may be accounted for in terms of general phonetic-physiological factors. In order to prevent air from escaping between the tongue and the palate during the closing stage of the plosive, and thus producing a fricative, a larger contact area is needed for the voiceless than for the voiced plosive since the air pressure is stronger for the voiceless than for the voiced plosive.

1. Introduction

A previous investigation of the English and Norwegian plosives /t/ and /d/, using EPG (electropalatography), showed a larger contact area between tongue and palate for /t/ than for /d/ in both languages. It was suggested that differences in intraoral air pressure during the articulation of voiceless and voiced plosives might account for the larger contact areas for /t/ than for /d/ \cite{1}. At the time of this investigation there were no available data for intraoral air pressure during the articulation of Norwegian consonants. A number of investigations of air pressure for English consonants, however, have reported higher pressure levels for /t/ than for /d/ (see for instance \cite{2} and \cite{3}). These investigations have also demonstrated variability in intraoral air pressure for plosives depending on the phonetic context in which they appear \cite{4}.

The aim of the present study is to obtain data for intraoral air pressure for the Norwegian plosives /t/ and /d/ and compare these with EPG tongue/palate contact patterns for the same plosives in order to see whether there is covariation between variation in air pressure and variation in size of contact area.

2. Database

The database consists of intraoral air pressure measurements and EPG tongue/palate contact patterns collected from two Norwegian female middle aged speakers reading eight different Norwegian words containing the consonant pairs /t/ and /d/. The test words were chosen in such a way that /t/ and /d/ appear both in initial and final position in connection with a narrow and an open vowel: din, tin, lid, lit, da’n, ta’n, bad, mat. (All the words are pronounced with long vowels). The words were produced in the frame sa _ a.

2.1. Test procedures

For the measurements of intraoral air pressure the test phrases were read in random order ten times for each test word with the main stress on the test word. A pressure transducer connected to a computer (see below) was placed in the subject's mouth during the reading. At the same time a conventional tape recording of the subject's speech was made for control purposes. The reading was made by each of the subjects at a self determined rate and loudness level. The loudness level was, however, controlled to see that it was relatively stable for both speakers throughout the recording session. This was done in order to preclude that variation in oral pressure could be attributed to variation in loudness level.

For the measurements of tongue/palate contact the test phrases were also read in random order ten times for each test word with the main stress on the test word. The subject was fitted with an EPG palate during the reading (see below).

2.2. Instrumentation for the measurement of air pressure

A Druck PDCR42 high performance pressure transducer was connected to a Hottinger Baldwin Messtechnik CP32 amplifier. Measurements were monitored and processed by a computer equipped with the data acquisition card AT-MIO-16E-1 from National Instruments. The pressure transducer with range 75 mbar, equivalent to 765 cm H\textsubscript{2}O, has previously been tested out in water waves with amplitudes in the range 0.1-50 cm (H\textsubscript{2}O) and periods close to 1s, finding good accuracy.

For the present measurements the transducer was statically calibrated using a 10 cm column of H\textsubscript{2}O. The
pressure transducer was relatively small – 2 cm long and 1 cm in diameter, including a protection case. It was fixed to a thin, stiff metal pin which was held by the subject. This kept the transducer in a stable position in the oral cavity. The transducer was found to interfere minimally with the subject’s articulation during the reading of these particular test words. The recorded time series of the pressure were lowpass filtered truncating frequencies higher than 50 Hz (Figure 1).

2.3. Instrumentation and data reduction for the EPG measurements

Electropalatography (EPG) is a recording technique where the informant carries an artificial acrylic palate, with 62 implanted electrodes, which is connected to a PC. When the tongue touches the palate, the contact patterns are displayed on the computer screen and recorded (see Figure 2). We have used a Reading EPG 3 for our investigation.

The EPG acrylic palate covers the alveolar ridge, the hard palate, and the front part of the velum. The palate does not cover the teeth. This means that any contact between tongue and teeth will not be registered.

The basis for this analysis were the EPG frames which show maximum lingual-palatal contact. As a measure for the area of contact in the frame with maximum contact the number of filled (activated) electrodes in the frame were counted.

3. Results

3.1. Intraoral air pressure

The maximum values in mm H₂O of pressure peaks for each /t/ and /d/ relative to a zero level were tabulated. From these values mean and standard deviation in mm H₂O were calculated (see Table 1).

Table 1 shows that there is a clear tendency for higher oral pressure peaks during the articulation of /t/ than of /d/. Collapsing the values for both subjects, the mean value for /t/ is 87 (SD 2) and for /d/ 66 (SD 2). This means that on the average the air pressure during the articulation of /t/ is 32 % higher than during the articulation of /d/. There are, however, some interesting differences between the two subjects. For Subject 2 the air pressure during the articulation of /t/ is 45 % higher than during the articulation of /d/ (/t/: mean 98, SD 3; /d/: mean 67, SD 3). For Subject 1 the difference in air pressure is not so marked. The air pressure during the articulation of /t/ is 17 % higher than during the articulation of /d/ (/t/: mean 98, SD 3; /d/: mean 67, SD 3). It is also noteworthy that for Subject 2 the air pressure for /t/ is always higher than for /d/ in the same phonetic context. For Subject 1, on the other hand, there is slightly more pressure for /d/ than for /t/ in one of the contexts, /a'n/da'n/.

3.2. Tongue/palate contact patterns

The number of filled electrodes in the frames with maximum contact for each /t/ and /d/ were tabulated. From these values mean and standard deviation were calculated (see Table 2). (Recall that the maximum number of electrodes in the EPG palate is 62.)
Table 2 shows that there is a clear tendency for larger areas of contact between tongue and palate during the articulation of /t/ than of /d/. Collapsing the values for both subjects, the mean value for /t/ is 42 (SD 0.4) and for /d/ 38 (SD 0.5). This means that on the average the contact area during the articulation of /t/ is 11 % higher than during the articulation of /d/. There are, however, clear individual differences between the two subjects. For Subject 1 the contact area is 4 % higher during the articulation of /t/ than of /d/ (/t/: mean 43, SD 0.4; /d/: mean 41, SD 0.4). For Subject 2 the difference is more marked. The contact area during the articulation of /t/ is 19 % larger than during the articulation of /d/ (/t/: mean 42, SD 0.6; /d/: mean 35, SD 0.7). It is also noteworthy that for Subject 1 there is a tendency to overlap (at 1 SD) in the size of contact area for /t/ and /d/ in the environment of the open vowel /a/. In the articulation of Subject 2 there is no overlap. (For Subject 1, there are in addition slightly more filled electrodes for /d/ than for /t/ in the context tin/din. Since the EPG palate does not cover the teeth, we do not know to what extent there is contact between the tongue and the teeth in this context – in view of the narrowness of the vowel, that is a possibility. Thus, we do not know whether there is additional contact for /t/ outside of the area registered by the palate.)

<table>
<thead>
<tr>
<th></th>
<th>/t/-tin</th>
<th>/t/-lit</th>
<th>/t/-ta'n</th>
<th>/t/-mat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject 1</td>
<td>43 (0.5)</td>
<td>46 (0.5)</td>
<td>41 (0.6)</td>
<td>41 (0.6)</td>
</tr>
<tr>
<td>Subject 2</td>
<td>45 (1.0)</td>
<td>41 (0.5)</td>
<td>41 (1.6)</td>
<td>40 (1.0)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>/d/-din</th>
<th>/d/-lid</th>
<th>/d/-da'n</th>
<th>/d/-bad</th>
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</thead>
<tbody>
<tr>
<td>Subject 1</td>
<td>44 (0.4)</td>
<td>41 (0.6)</td>
<td>40 (0.3)</td>
<td>39 (0.6)</td>
</tr>
<tr>
<td>Subject 2</td>
<td>39 (1.0)</td>
<td>31 (1.4)</td>
<td>35 (0.8)</td>
<td>35 (1.3)</td>
</tr>
</tbody>
</table>

4. Discussion

First of all, our data clearly indicate, like data from other languages, that the oral air pressure during the articulation of voiced stops is lower than during the articulation of voiceless stops. This can be accounted for in terms of the articulatory mechanisms used to produce voiced stop consonants. Voicing requires airflow across the vocal folds. In order to produce an airflow in the closed system of stop consonants, a transglottal pressure drop must be created. This is presumed to result from an enlargement of the supraglottal cavity during the stop phase. Different mechanisms have been suggested for enlarging the cavity: e.g., active or passive expansion of one or more walls of the cavity, or lowering of the larynx [5], [6]. It has also been suggested that there may be a certain escape of airflow through the nasal passage during the articulation of voiced plosives [5].

We have seen that in the case of our Subject 1 there was a tendency to overlap between the air pressure for /t/ and /d/ in the context of the vowel /a/. We have also seen that the general difference in pressure between the voiced and the voiceless cognates was less marked in the case of Subject 1 than of Subject 2. It is possible that this difference is due to nasal emission during the closing phase of the stops in the articulation of Subject 1. It has been noted that momentary relaxation of the velum without the overall acoustic target having been affected may occur [7]. Nasal emission may also occur as an artifact from movement of the pressure transducer. This has been noted to occur most frequently in phonetic contexts associated with low vowels, like [a], and extensive mandibular movement [8].

Secondly, our data indicate a clear tendency for a larger contact area between tongue and palate during the articulation of /t/ than of /d/ for both subjects. We assume that this difference is linked to the difference in intraoral air pressure during the articulation of the two stop consonants. The air pressure is higher during the articulation of /t/ than of /d/. The larger contact area for /t/ prevents air from escaping orally during the closure phase of /t/ and thus producing a fricative sound instead of a stop. Since the air pressure is lower during the articulation of /d/, a smaller contact area will suffice in order to prevent oral escape of air. This assumption is supported by the fact that there is clear covariation between air pressure and contact area for both subjects. Subject 2 has the largest differences, both in air pressure and in tongue/palate contact area during the articulation of the two stops. Subject 1 has smaller differences both in air pressure and in contact area.

A possible explanation for the relatively small difference in air pressure and tongue/palate contact area for /t/ compared to /d/ during the articulation of Subject 1 may be nasal emission of air during the articulation of plosives. As mentioned above, this tendency has been found in other investigations, and in particular in the articulatory context of open vowels. It is in this context that Subject 1 has a slightly higher air pressure value for /d/ than for /t/ and a tendency to overlap in the size of tongue/palate contact area.

5. Conclusion

On the basis of these data we have found a clear covariation between intraoral air pressure and the size of the contact area between tongue and palate during the articulation of voiced and unvoiced plosives. There is in general a higher oral air pressure and more tongue/palate contact during the articulation of /t/ than of /d/, and the subject with the largest differences in oral air pressure also shows the largest differences in size of contact area. We suggest that this covariation is due to the need of a full closure during the articulation of plosives. For the subject with less marked differences in both air pressure and contact area, and even cases of overlap particularly in the context of open vowels, we suggest that nasal emission of air during articulation may be a possible explanation. A topic for further study, then, would be to investigate oral and nasal airflow during the articulation of stops for our two subjects.
6. Acknowledgements

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7. References


