THE SENSITIVITY OF INTRAORAL PRESSURE IN CONSONANTS AND CONSONANT CLUSTERS TO FOLLOWING VOWEL CONTEXT IN GERMAN

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ABSTRACT

Most studies of intraoral pressure (IOP) variation have focused on consonantal voicing, place, and manner, but indirect data suggest that IOP during consonants may also show coarticulatory effects due to surrounding vowels. Here, we explore how IOP varies in consonants and consonant clusters of two German speakers depending on following vowel height. Our data suggest that IOP varies consistently with vowel context, particularly with respect to the duration of the IOP pulse. Comparison with simultaneously-recorded EPG data indicate that the IOP results reflect longer articulatory contact time in the high vowel context.

Keywords: Intraoral pressure, obstruents, vowels, EPG

1. INTRODUCTION

When the vocal tract is obstructed, pressure within the supraglottal vocal tract (intraoral pressure; hereafter IOP) increases. It is well-known that peak IOP levels and the shape of the IOP trajectory vary systematically with consonant voicing status (e.g., [1–4]) as well as with manner status (viz., stops vs. fricatives, cf. [5–7]). Articulatory placement may also affect IOP: Ohala [8] observed that more anterior consonants provide speakers with greater opportunities for aerodynamic management (cavity enlargement).

There is limited aerodynamic evidence for vowel context effects on IOP. Netsell [9] reported slightly but significantly higher IOPs in repetitions of /pi/ compared to /pa/. This would be consistent with data showing that speakers have higher jaw positions during consonant closures preceding high vowels than low vowels (e.g. [10]). Indirect evidence also suggests that IOP is sensitive to vowel context. One explanation for longer VOTs following [k^h] as compared to [t^h] or [p^h] (e.g., [11]) is that a higher pressure buildup behind the posterior constriction is discharged over a longer period of time. Klatt [12] also reported that VOTs were longer for stops releasing into high vowels as compared to lower vowels. This too could be explained in terms of aerodynamic parameters: Releasing the built-up pressure into a smaller cavity (as for a high vowel) should result in a slower pressure discharge due to increased resistance downstream of the occlusion.

Despite such suggestions that vowel context may be relevant to understanding vocal tract aerodynamics around obstruents, few studies have directly explored this topic. In this paper, we investigate IOP trajectories during consonants or consonant clusters in two speakers of German where the following vowel is either high (/i/ or /ɪ/) or low (/ɑ/).

2. METHODS

2.1. Instrumentation and pre-processing

A more complete recording protocol is provided in [13]. Briefly, we simultaneously recorded electropalatographic (EPG) data; IOP; and acoustics. The EPG data were obtained using a Reading EPG 3 system, with custom-made palates for each speaker, and a sampling rate of 100 Hz. The IOP signal was collected using an Endevco 8507C-2 pressure transducer fitted into a small plastic tube at the posterior end of the EPG palate. A separate tube passed around the teeth outside the oral cavity recorded atmospheric pressure, so that the IOP signal represents the difference between IOP at the sensor site (posterior end of the hard palate) and atmospheric pressure. The IOP data were sampled at 1859 Hz using PCQuirer. Finally, an acoustic signal was recorded to DAT at 44 kHz. After recording, all data were imported into Matlab for further processing.

The IOP data were then further processed to facilitate interactive measurement. The data were low-pass filtered using a kaiser window with 40 Hz passband and 100 Hz stopband edges and a damping factor of 50 dB. From this smoothed signal, first and second derivative signals (velocity and acceleration, respectively) were computed in Matlab. Events in the velocity and acceleration signals were used to identify pressure landmarks, as described below.

2.2. Speakers

The full corpus includes data from 8 speakers of Standard German (5 men and 3 women). The current analysis considers data from 2 women, SF and SK. These speakers were chosen for two reasons: (a) They cover a range of speaking styles: Speaker SK used a fairly slow and careful speaking style, whereas SF used a faster, more colloquial style. (b) Sex differences in laryngeal height and supraglottal size may affect IOP variations behind an occlusion. Thus, in this exploratory study, we held speaker sex constant.

2.3. Speech stimuli

Speech stimuli were constructed to provide insight into articulatory contact and IOP patterns in a variety of consonants and consonant clusters of German. A set of 42 real German words was assembled, and these were placed into compounds and short utterances so as to vary the length of the consonant string. Although the compounds and utterances were phonotactically and syntactically legal, the utterances were mostly semantically nonsensical. For each speaker, a fully randomized list was prepared including all utterances x 10 repetitions. Speakers read the items from the randomized printed list, with instructions that each utterance should be produced as an independent utterance, with a falling intonation contour.

The current analysis focuses on small subset of the data, namely those utterances including singleton /t/ and /ʃ/ as well as /ʃt/, /st/ and /tʃ/, preceding the vowels /i/, /ɪ/, or /ɑ/. Specifically, we contrast the following word pairs:

Ich nasche Taschenstelle/Tischstelle
Ich nasche Schafstelle/Schiffstelle
Ich nasche Stachelstelle/Stichstelle
Ich nasche Tschadstelle/Tschibostelle
Ich nasche Stalinstelle/Stilstelle

In most cases, the target syllables differ only in the vowel. The words *Stil* and *Stalin* are usually produced with /ʃt/, but /st/ is also possible. Speakers were instructed before the recording session to produce /st/ in these words.

2.4. Data Processing: IOP

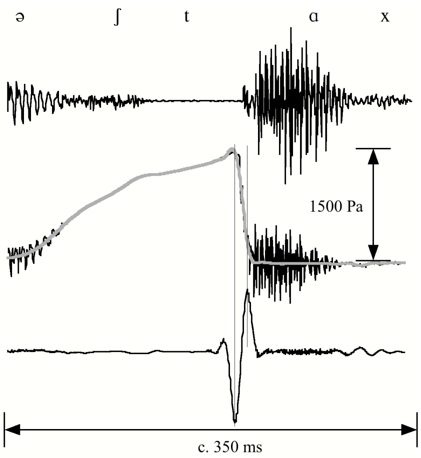
An example of the acoustic and aerodynamic signals is shown in Fig. 1. The first step in processing was to correct for temperature-related drift in the pressure signal over the course of the recording session. A pressure minimum in the vowels before and after each target consonant/cluster was obtained, using zero-crossings in the pressure velocity signal, and the lowest of these values was subtracted off the entire file.

To demarcate the pressure decrease after consonant or cluster release, two events were defined: Where a fricative preceded the vowel (including affricates), the maximum pressure value in the fricative was labeled, using zero-crossings in the first derivative signal. Where stops preceded the vowel (including fricative+stop clusters), the beginning of the rapid pressure descent following oral release was labeled, using a minimum in the second derivative signal (cf. Fig. 1). The absolute maximum was not used here because we observed that in some situations the pressure maximum occurred well before the release. Although somewhat different measurement criteria were used for stop vs. fricative release, the purpose of both was to identify where the consonant began to release into the vowel. The end of the pressure release into the vowel was marked using the peak in the second derivative signal that corresponded to the pressure flattening off to its vowel-like level (see Fig. 1). Finally, individual tokens were extracted for a region centered around the onset of the pressure decrease corresponding to consonant/cluster release, and averaged.

2.5. Data Processing: EPG

To characterize differences in articulatory contact as a function of vowel, two summary measures were obtained from the EPG data: Percentage of contact (PC) across the whole palate, and the degree of anterior contact (ANT). Acoustic events (onset of frication noise or stop closure, offset of frication noise, stop release) were used to delimit the time regions for the EPG measures. The data were interpolated to a proportional time scale and averaged.

Figure 1: A portion of *Ich nasche Stachelstelle* produced by speaker SF. From top to bottom: Acoustics; original (black) and smoothed (grey) IOP; acceleration of IOP.



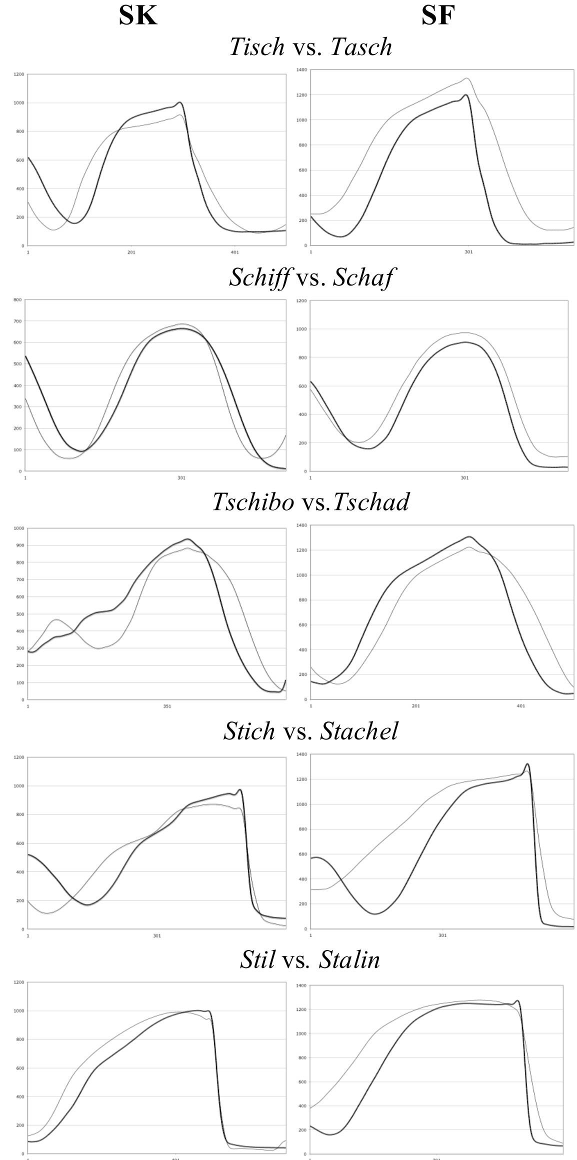
3. RESULTS

Figure 2 shows the averaged smoothed IOP data for the two speakers. The traces represent averages of 10 tokens.

The data show that, for most consonants or consonant clusters, vowel context affects the IOP trajectory. For both speakers, the main consistent effect of vowel context appears to be lengthening the duration of the IOP pulse associated with the consonant in the high vowel context. Vowel effects are somewhat more extreme for SF, the speaker with the faster, more casual speaking style. Vowel influences on the maximum pressure levels in the clusters are inconsistent across consonants and speakers.

Figure 3 shows the averaged percentage of contact (PC) obtained from EPG for a subset of the utterances in the two speakers. In the case of the single fricative, vowel context mainly lengthens the duration of the constriction. Comparing the EPG and pressure data, we see that this is reflected in SF's pressure data, but not SK's. In the affricate, a rapid drop in PC parallels a faster decrease in pressure. For the cluster, both speakers show higher PC values in the high vowel context; SK shows a durational difference as well. Comparing this with the pressure data, it is evident that small differences in percentage of contact do not necessarily lead to higher pressures; in fact, here, both speakers have slightly higher peak pressures for the /ɑ/ context.

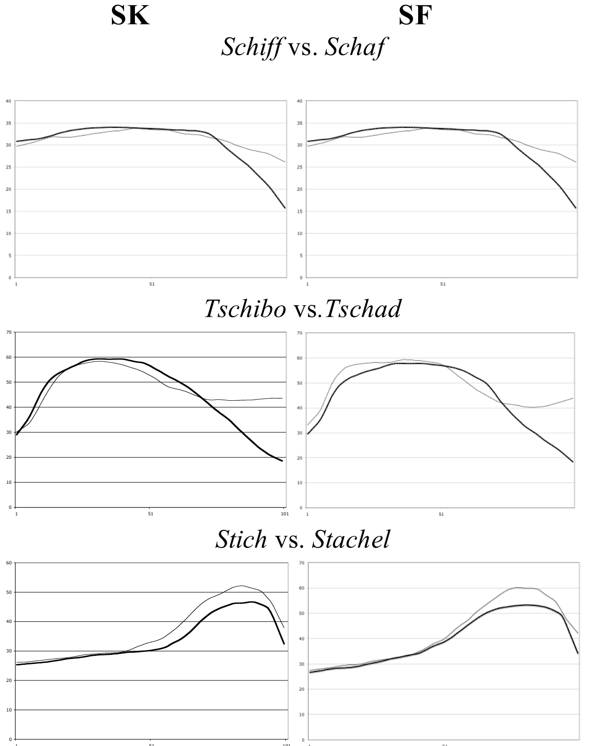
Figure 2: A portion of *Ich nasche Stachelstelle* produced by speaker SF. From top to bottom: Acoustics; original (black) and smoothed (grey) IOP; acceleration of IOP.



4. DISCUSSION

Our data show that the time course and, in some cases, the absolute level of IOP is sensitive to vowel context. Generally speaking, elevated IOP is maintained for a longer period of time in high vowel contexts. Comparing the IOP with EPG suggests that the IOP results reflect the duration of

Figure 3: Percentage of contact (PC) as a function of vowel for the two speakers (SK on the left; SF on the right). In each plot, the thin line represents the /i/ or /ɪ/ context and the heavy line represents the /ɑ/ context.



articulatory contact or constriction. A shorter constriction time for the low vowel context may be an accommodation for the longer opening movement durations other authors have observed for low vs. high vowel contexts (e.g., [14]). Absolute levels of articulatory contact do not necessarily lead to higher pressures, however.

These results are consistent with aerodynamic explanations for longer VOTs preceding high vowels [12]. They also indicate that simple measures of peak pressure are not enough to characterize IOP differences as a function of phonetic context. In the future, we plan to use these data to inform aerodynamic modeling of the vocal tract.

5. ACKNOWLEDGEMENTS

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