# Effects on speech of introducing aerodynamic perturbations

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## ABSTRACT

Certain contextually-predictable phonetic variations have been hypothesized to be due to differing aerodynamic factors: (1) the F0 perturbation on vowels following voiced and voiceless obstruents, (2) the slight differences in Voice Onset Time, and (3) devoicing of back-articulated stops such as [ɡ]. To test these hypotheses we introduce two techniques that create artificial perturbations in pharyngeal pressure thus causing changes in the magnitude of the pressure drop across the glottis and the pressure drop across the supraglottal constriction. One method involves passively venting oral air through a tube inserted between the cheeks and behind the upper molars. The other method involves connecting a vacuum source to a catheter inserted into the pharynx via the nasal passage. Preliminary data suggest that the F0 perturbation characteristic of voiced / voiceless obstruents is not significantly affected by the aerodynamic perturbation. The other two effects are.

## 1. INTRODUCTION

One of the main tasks in phonology is to find the "sames" amid variable pronunciations. Traditionally this was done with a purely distributional analysis, that is, searching for variants of suspected functionally equivalent sounds that were in 'complementary distribution'. Phonetically-based phonology augments this method by establishing that pronunciation variation can be linked quantitatively and lawfully to hypothesized causes [7][9]. In some cases one can count on natural variation in speech to produce changes in the independent variable and then attempt to find lawful covariation in the dependent variable. For example, Chang [1] studied the slight variations in Voice Onset Time (VOT) after voiceless stops: greater VOT preceding high, close, vowels and sonorants, lesser VOT preceding open vowels [4][11]. He tested the hypothesis that the transglottal pressure drop required for the initiation of voicing was delayed when the air accumulated in the oral cavity during the stop took longer to exit due to the greater resistance offered by the high, close, segments following the stop [10][11]. He measured VOT and the fall time in the oral pressure impulse following the release of voiceless stops in the context of different following sonorants. His finding of a high positive correlation between oral pressure fall time and VOT was offered as support for the aerodynamic hypothesis. It was assumed that the timing of glottal abduction was not different for these different conditions. Larson [6] presents evidence supporting that assumption.

Another way to establish a lawful connection between a posited independent and dependent variables, in fact, the classical way in experimental disciplines such as physics, chemistry, and physiology, is to contrive to directly create changes in the independent variable, i.e., to have such variation controlled by the experimenter, not by nature. In many cases this is preferable because, ideally, one can then have more confidence that only the one variable has been introduced. We report here on some initial attempts to develop methods to change some of the aerodynamic variables thought to create certain contextual phonetic variation. These contextual variations are:

**Consonantally-caused F0 variation**: It is well documented that in many languages voiced and voiceless consonants perturb F0 on following vowels [3]. This is presumed to be the origin of several cases of the historical development of tones [3]. The phonetic cause of the F0 perturbation is controversial. It has been attributed to aerodynamic factors (the rate of airflow is assumed to be greater on the release of a voiceless stop than on the release of a voiced one) [5]. Others offer reasons why it is probably due to differences in the tension of the vocal cords [2][3][8].

**VOT Variations**. It is generally well established that voiceless stops' VOT may show slight variations as a function of the nature of the following sonorant that the stop is released onto. High, close, vowels, and sonorant consonants give rise to a longer VOT than to low, open, vowels [4][11]. Ohala [11] attributes this to aerodynamic factors: the onset of voicing is delayed if the oral pressure impulse from the stop decays more slowly due to the exiting air encountering greater resistance to airflow. As mentioned above, there is evidence supporting this hypothesis [1][6].

**Obstruent Devoicing:** It is well known that because obstruents involve an accumulation of air in the oral cavity, they cause a decrease in the pressure drop and thus airflow through the glottis. This tends to inhibit and possibly extinguish voicing [12][15]. The stops in English usually labeled 'voiced' are frequently voiceless. They are usually voiced between sonorants although even in this environment the velar stop may still be voiceless. Are any of the instances of "voiced" stop devoicing in English due to aerodynamic factors?

## 2. EXPERIMENTAL METHODS

Two methods were used to produce involuntary changes in pharyngeal pressure during speech. The first (previously



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reported in [14][16]], involves inserting a plastic catheter with a large inner diameter (8 mm) into the post-palatal region of the oral cavity via the buccal sulcus (the space between the upper teeth and the cheek) and the gap behind the last molar. A stiff wire inside the plastic tube helps to maintain the right-angle bend of the tube behind the molars. (This method works best with speakers who have had one of their rearmost upper molars extracted.) The external end of the tube can be intermittently opened or closed by the experimenter. With care, this could be done without the speaker knowing when the tube was open or closed. This will be referred to as the ***'buccal vent'*** method.

A second method involves a small tube (i.d. 3 mm) inserted into the pharynx via the nasal passage. This tube is connected to a vacuum source.(a water aspirator, which produces a vacuum based on the Bernoulli effect). Connected in series with the tube are a valve and a collection vessel (to collect mucus and saliva). The pharyngeal pressure can be reduced by sucking air out through the vacuum system. (A tube small enough to be tolerated by subjects in the nose would not, by itself, produce sufficient pressure decrement to yield a significant effect on speech aerodynamics, unlike the case involving the buccal vent method. Thus connecting this tube to a vacuum source was necessary.) Opening and closing the valve will draw out some of the pharyngeal air thus reducing its pressure. A smaller tube (i.d. 1.5 mm), also inserted into the pharynx via the nasal passage, is connected to a pressure transducer in order to measure pharyngeal pressure. We refer to this as the ***'nasal vacuum'*** method. With this method we were unable to conceal the moments when the valve was open (connected to the vacuum source) and when it was closed. When connected to the pharyngeal tube the vacuum system made a fair amount of noise—mainly from the action of mucus that had accumulated inside the tube. In fact, mucus accumulation remains one of the major problems with this method. This was also true of the tube measuring pharyngeal pressure. The mucus could be temporarily removed from the pharyngeal pressure tube by connecting it to the vacuum system.

The two methods produce similar results. Each has advantages and disadvantages. Some subjects tolerate the buccal vent method better than the nasal vacuum method but the latter permits more natural speech and has the additional advantage of permitting study of velar consonants.

The buccal vent method was utilized with two subjects, JJO an adult male native speaker of American English (the first author) and MJS, an adult native Catalan and Spanish bilingual, although for this preliminary study, speaking English. The nasal vacuum method was used with three subjects, the same two just mentioned, and a third DM, an adult native speaker of American English. A variety of test utterances, e.g., /bɑ, pɑ, di, ti, trɑ, twɑ, ɑgɑ/, etc. were uttered in the frame sentence 'say ___ twice' [ sɛɪ ___$t^h$wɑɪs].

## 3 RESULTS

The results reported here are preliminary in that we had few subjects and relatively few tokens per word type. The average values for syllable types with and without reduced pharyngeal pressure are based on four to six tokens. Also, as mentioned, in the case of the nasal vacuum method the subject would be able to detect when the vacuum was applied and when not. In fact we observed that often although the pharyngeal pressure was reduced when the vacuum was connected for a given token, in the immediately following token the pharyngeal pressure was often restored to be within the baseline range. If subjects are somehow compensating for the reduced pressure, this is interesting by itself but we were unable to pursue this further. In any case the effect of the vacuum was to increase the incidence of a lower pharyngeal pressure, not to guarantee it. Both the nasal vacuum and the buccal vent succeeded in lowering pharyngeal pressure more in the case of voiced obstruents than voiceless ones. This is consistent with earlier results [14] where it was suggested that voiceless obstruents would show less of an effect of venting pharyngeal pressure since, their having little glottal resistance, are more quickly resupplied with air from the pulmonic air reservoir.

**Consonantally-caused F0 variation**: Figures 1 and 2 give average values for F0 contour following the voiced and voiceless fricative /s/ and the voiced stop /b/, respectively. As is evident, there was no consistent difference in the F0 contour following voiced and voiceless consonants, suggesting that some other factor, presumably vocal cord tension, plays a greater role in creating the different F0 contours than does transglottal pressure drop.

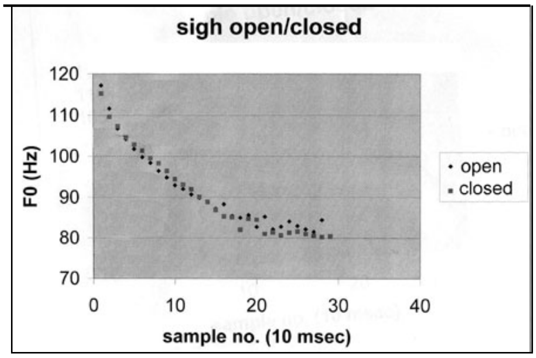


**Figure 1.** F0 contour after the [s] of "sigh" [ sɑɪ], with and without the pharyngeal pressure being vented by a tube inserted through the buccal sulcus. Subject JJO.

**VOT Variations**. There was a weak correlation between the pharyngeal pressure measured at the moment of stop release and the VOT for a given syllable type. Fig. 3 shows such a correlation for the syllable [twa] (subject MJS). The correlation here is r = .52. The effect of different oral pressure is apparently small but so is it in the naturally occurring VOT differences. This supports that part of the original hypothesis addressed (see above) that VOT can show slight variations as a function of the quantity of air that remains to be evacuated after the release of a stop.

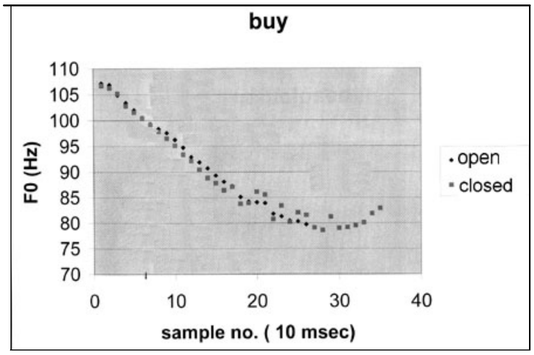


**Figure 2.** F0 contour after the [b] of 'buy" [ baɪ]. See caption to Fig. 1. Subject JJO.

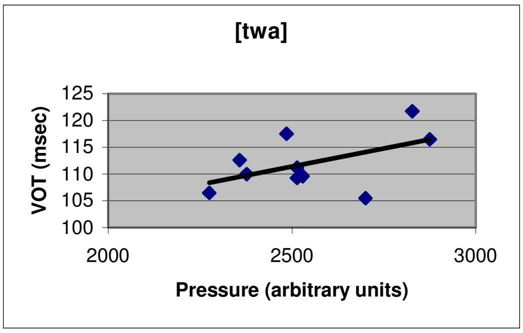


**Figure 3.** VOT as a function of the pharyngeal pressure at the moment of stop release for the syllable [twɑ]. Pressure variation Subject MJS.

**Obstruent Devoicing.** Given the frame sentence, the word-initial stops /b/ /d/ were also inter-sonorant and were typically voiced throughout whether the pharyngeal pressure was reduced or not. However, subject DM's intervocalic [g] in the test utterance [ɑgɑ] was typically voiceless in the normal condition. See Fig. 4. However when the pharyngeal pressure was reduced with the nasal vacuum method, these /g/s became voiced. See Fig. 5. Evidently in this case the typical voicelessness of the velar stop is a function of the too small pressure drop across the glottis. Velars are known to be more subject to this aerodynamic voicing constraint because they have less surface area behind the point of constriction. This limits their capacity for passive enlargement which is necessary to keep the pharyngeal pressure low and the transglottal pressure drop high enough to support voicing [12][13].

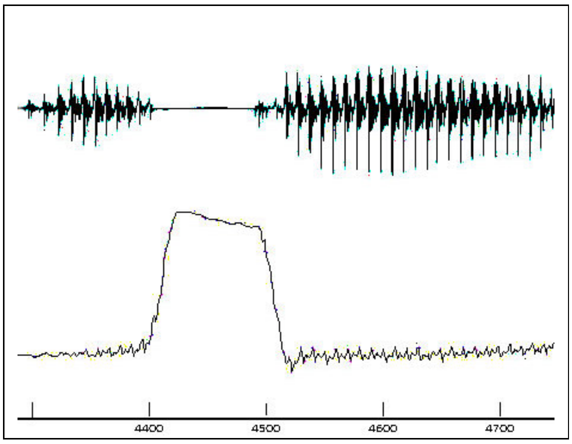


**Figure 4.** Subject DM's /ɑgɑ/ under normal conditions. Top: microphone signal; bottom, pharyngeal pressure.

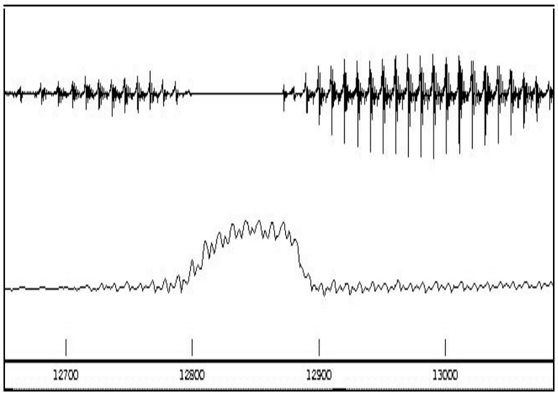


**Figure 5.** Subject DM's /ɑgɑ/ when pharyngeal pressure was reduced by the nasal vacuum method. In comparison to Fig. 4, the [g] is voiced (evident in the pressure signal's microphonics, if not the air-borne acoustic signal).

## 4. CONCLUSIONS AND DISCUSSION

Although the results reported here are preliminary, we hope they have accomplished two things. First, they help to test competing hypotheses about the physical phonetic causes of certain kinds of contextually predictable variation in speech. The focus was on aerodynamic factors, in particular types of phonetic variation said to be due to variations in the pressure drop either across the glottis or across the oral cavity constriction. We tentatively conclude that the consonantally-induced F0 variations on vowels following voiced and voiceless consonants are not noticeably affected by variations in the transglottal pressure drop. However, there is evidence that fine variations in VOT is influenced by


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variations in the trans-oral constriction pressure drop (in other words, in the amount of air that has to exit the vocal tract following the release of voiceless stop). In addition, there is evidence that in some cases, obstruent voicing/devoicing—specifically that of /g/ in English—is influenced by the transglottal pressure drop.

Second, we hope that this work presents some useful additions to the arsenal of techniques for doing *in situ* experiments on speech processes in the classic experimental method where one controls a crucial posited independent variable and looks for a predicted corresponding variation in a dependent variable.

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