A PHONETIC STUDY OF SUBGLOTTAL PRESSURE EFFECTS ON STRESS AND FUNDAMENTAL FREQUENCY

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ABSTRACT

An important issue in speech production is to understand the relation between subglottal pressure (Ps), fundamental frequency (f_o) and stress. Attempts have been made to identify the contribution of Ps and f_o on stress. An important point is to determine whether stress is realised by an increase in Ps (therefore intensity) and its effect on f_o. Thus it is important to know whether f_o variations on stress are voluntary and programmed or not. This paper addresses this issue by studying f_o and Ps in a set of English sentences produced by 1 native English speaker. Ps and speech were recorded simultaneously and Ps was measured by direct tracheal puncture. Results show that in declarative sentences there is an increase of Ps on stress accompanied by a fall of f_o. Interrogative sentences have an increase of Ps on stressed syllables with a lower and slightly falling f_o.

Keywords: stress, intonation, subglottal pressure, fundamental frequency, physiology.

1. INTRODUCTION

In speech sentences one important global attribute is the tendency of fundamental frequency (f_o) to decline gradually from the beginning to the end, this phenomenon is usually referred to as declination. One important question related to declination is to know if it is the result of voluntary f_o changes or physiologically determined therefore involuntary fluctuations. Ohala [8] mentions that the cause of declination remains an unresolved issue. Hart et al. [4] mentioned the perceptual relevance of declination and notably the fact that it might be linguistically relevant. These authors emphasise that declination is not necessarily the product of voluntary control since the outcome of involuntary mechanisms can also result in linguistic information.

This issue is central to the understanding of the relation between subglottal (Ps) pressure and f_o, particularly in intonational phenomena. What is the contribution of Ps to f_o at sentences level and in speech in general, and how do they interact? Although there is an abundant literature discussing this problem, we can reasonably assume that f_o is largely controlled by intrinsic and extrinsic laryngeal muscular adjustments and that the main contribution of Ps to f_o is to raise the baseline in function of the intensity of speech. The higher the Ps and intensity, which are directly correlated, the higher the baseline will be [2]. During speech, Ps shows a relatively constant and slightly decreasing value between an initial rising phase and a final falling phase. In addition, there are modulations of Ps that are due to changes in the glottal or oral resistance and due to stress phenomena. One question arising from this is: how is the relatively constant Ps achieved despite the continuously decreasing lung volume? During normal exhalation, there is a mechanical elastic recoil force at play. This originates from the rib cage and the lungs. The deeper the inspiration, the greater the elastic recoil. Along with these mechanical factors, exhaling is often prolonged during speech by the action of abdominal and internal intercostal muscles. Therefore claims such as those made by Hart et al. [4] that a serious candidate for explaining the declination of f_o of an utterance is the slow decrease of Ps over the time course seem to be debatable. However they admit that several additional mechanisms effecting declination are conceivable.

In regard to stress, an important question is: does respiration have an active role in the production of stressed syllables? Ladefoged [7] showed the positive role of respiration in the implementation of stress. It was demonstrated that for every stressed syllable there is an increase in Ps. This means that the increase of Ps occurring with stress is mainly due to changes in activity of the respiratory muscles.

This paper tries to contribute to the identification of the possible physiological mechanisms responsible for declination and to the explanation of interplay between Ps and f_o in stress phenomena. We examined the production of a set of English sentences where both intonation and stress position were varied to bring out the relation between f_o and Ps.

2. MATERIAL AND METHOD

Data consisted in a set of 36 sentences that were recorded with one native English subject who repeated each of the selected sentences 3 times (Table 1). Groups 1/4 and 2/3 consist of respectively 3 and 4 target words by varying the carrier sentence "*say ... again*" / "*repeat ... twice*" which result in respectively 6 and 8 sentences. Group 5 contains 4 pairs of declarative / interrogative sentences which differ by the position of stressed syllable (in bold).

Table 1: 5 groups of recorded sentences.

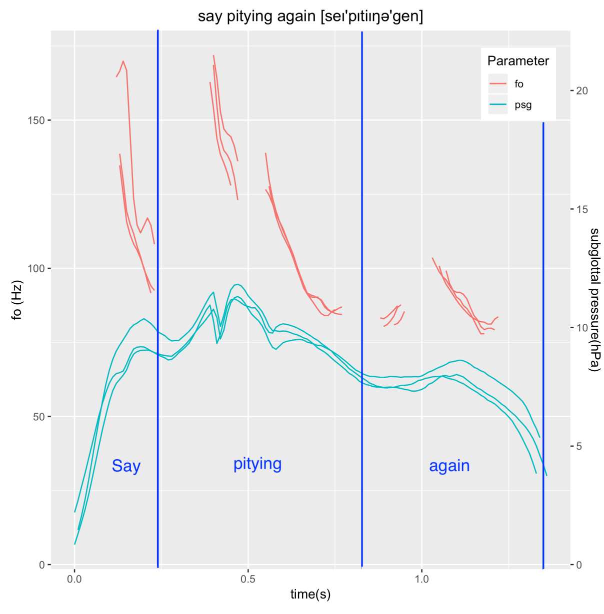
Group 1
1/5. (say / repeat) pit (again / twice).
2/6. (say / repeat) pity (again / twice).
3/7. (say / repeat) pitying (again / twice).
4/8. (say / repeat) pityingly (again / twice).
Group 2
9/12. (say / repeat) play (again / twice).
10/13. (say / repeat) playful (again / twice).
11/14. (say / repeat) playfully (again / twice).
Group 3
15/18. (say / repeat) photo (again / twice).
16/19. (say / repeat) photographer (again / twice).
17/20. (say / repeat) photographic (again / twice).
Group 4
21/25. (say / repeat) man (again / twice).
22/26. (say / repeat) manage (again / twice).
23/27. (say / repeat) managerial (again / twice).
24/28. (say / repeat) jeer (again / twice).
Group 5
29./33. Jenny's **pie** is pretty.
30./34. Jenny's pie is **pre**tty?
31./35. Je**nny's** pie is **pre**tty.
32./36. **Jen**ny's pie is pretty?

Subglottal pressure (Ps), intraoral pressure (Po), oral airflow (Oaf) and the acoustic signal were recorded synchronously. Ps was measured by tracheal puncture using a needle inserted in under the cricoid cartilage. The recording procedure preserved the rights and welfare of human research subjects, in respect of the ethical committee's rules at the Erasme Hospital, Université Libre de Bruxelles. The needle placement was made after administering 2% Xylocaine injection for local anaesthesia. A plastic tube linked to a pressure transducer was connected to the needle. Po measurements were obtained using a small tube inserted into the oropharynx through the nasal cavity. Oaf data were collected with a rubber mask placed over speakers' mouth. The acoustic signal was recorded with an AKG C 419 directional microphone positioned at a stable distance of 4 cm from the rubber mask. The Ps and Po tubes, the Oaf mask, and the microphone were connected to the *Physiologia* workstation; a multi-parameter data acquisition system allowing simultaneous recording of the speech signal and various aerodynamic parameters. The data acquisition and signal processing were handled with *Phonedit*. f_o values are computed using Praat pitch detection algorithm.

3. RESULTS

All three repetitions of each sentence were superimposed in the same graphic, as the following figure suggests, both f_o and Ps values and their variation are relatively consistant throughout repetitions (Figure 1). Each f_o segment corresponds to the voiced part of the sentence, the falling of f_o value within each segment is remarkable, and all results confirm that each stress syllable has a notable increase of Ps. The first derivative of each repetition was then computed by taking a time step of 10 ms (Figure 2)

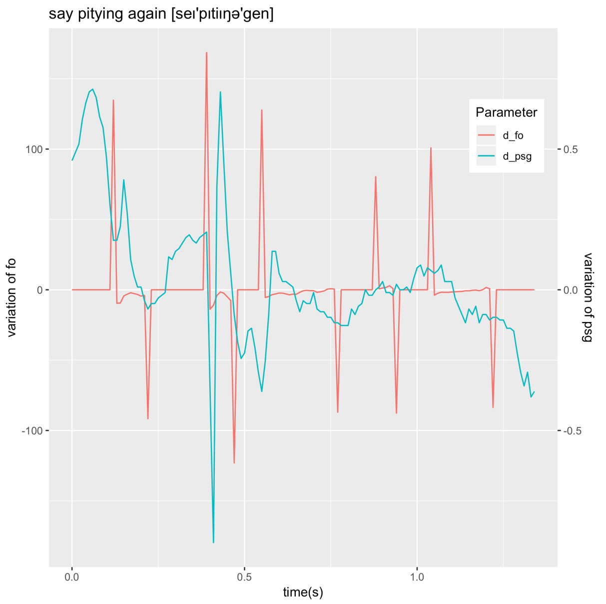
Figure 1: Variation of f_o and Ps of sentence 2. (group 1)



The first derivative shows the variation of f_o and Ps. Each positive-negative pic of the derivative of f_o corresponds to the limit of voiced segment of the speech. A clear initial rise and final fall can also be located using the first derivative, both the end of the final fall and the start of the initial rise correspond to the first and the last zero-crossing of the derivative of Ps.

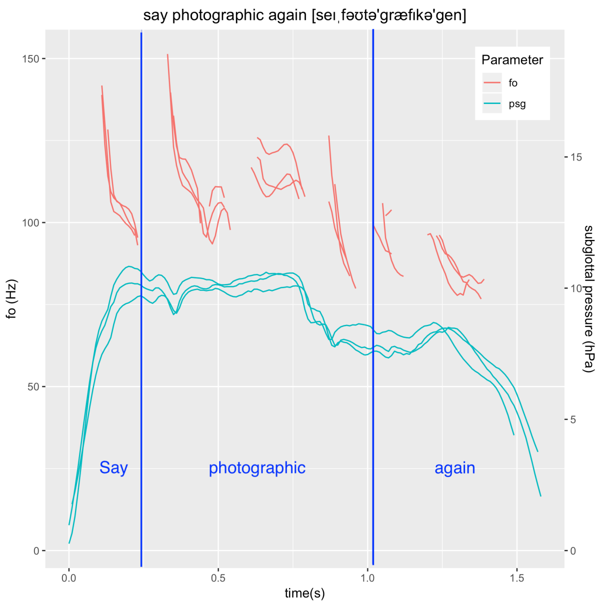
The rapid falling f_o segment (between each posi-

Figure 2: First derivative of f_o and Ps of sentence 2 (group 1)



tive and negative pic) corresponds to an increase of Ps, and it is prominent for stressed syllable.

Figure 3: Variation of f_o and Ps of sentence 17 (group 3)



3.1. Declarative vs. Interrogative

The comparison of figures 4 and 5 show the differences between declarative and interrogative sentences, whereas f_o in declarative sentences have always a rapid falling pattern, in interrogative sentences it is shorter and more flat.

Figure 4: Variation of f_o an Ps of sentence 30 (group 5)

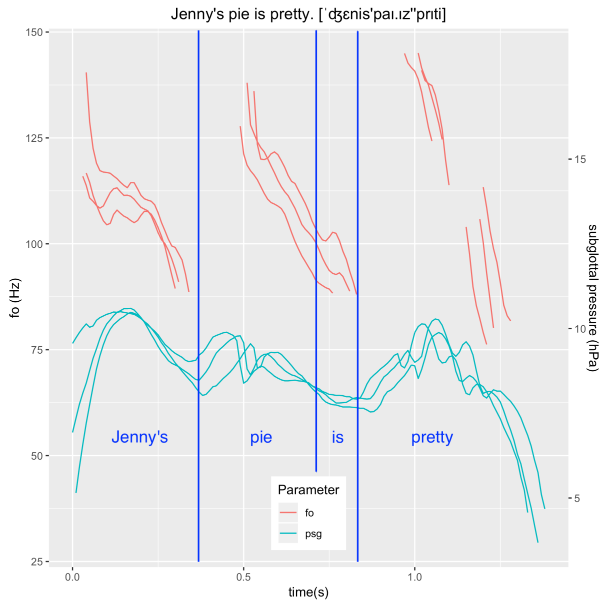
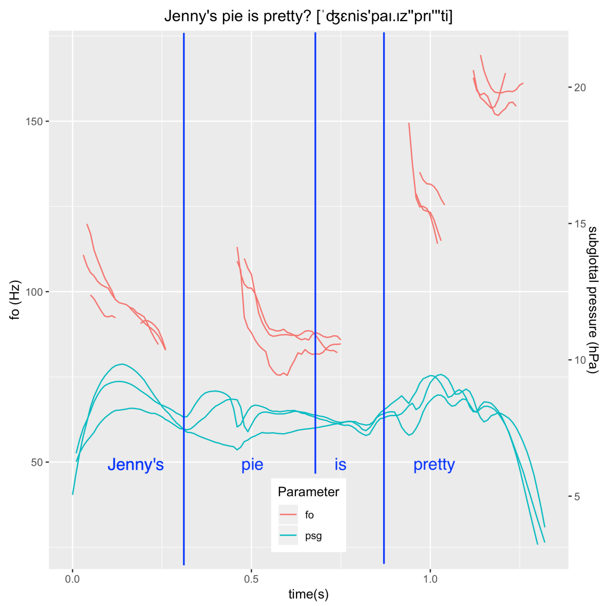


Figure 5: Variation of f_o an Ps of sentence 34 (group 5)



The comparison of the first derivative (figure 6 and 7) shows that, although the f_o pattern at the end of the sentence is completely different (falling for declarative and rising for interrogative), the variations of Ps are nearly the same for these two modality, suggesting that f_o is controlled independently of

Ps.

Figure 6: First derivative of f_o an Ps of sentence 30 (group 5)

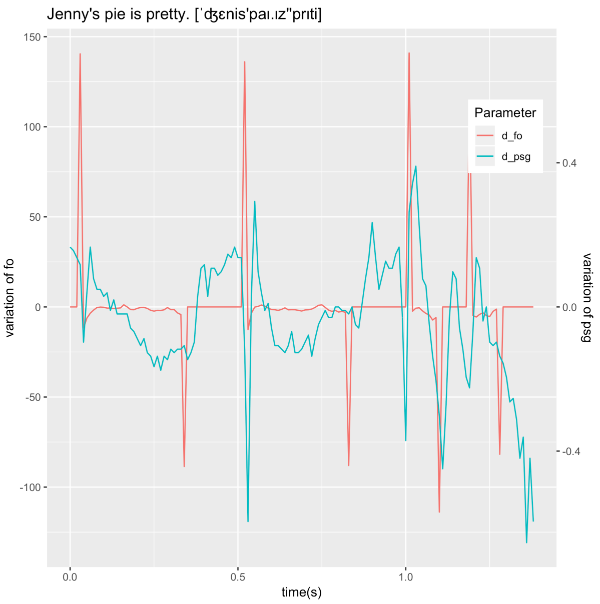
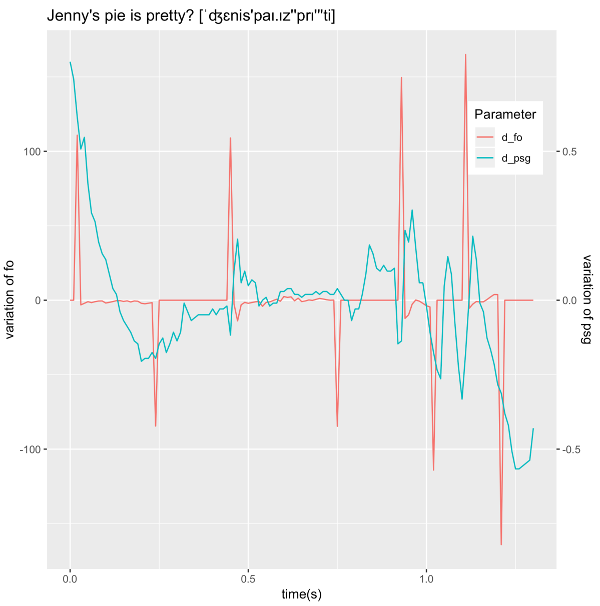


Figure 7: First derivative of f_o an Ps of sentence 34 (group 5)



4. DISCUSSION

The first point to mention is that our data confirm previous works done by [3] and [7] about the contribution of Ps to stress. The data also show clear examples of f_o declination on declarative sentences and f_o rise in interrogative sentences.

The literature generally assumes that the question of the phonetic correlates of stress is an intricate one [6]. For example, the interpretation of the physiological and acoustic correlates of stress is difficult to interpret because of the ambiguous role of intensity in the perception of stress [6]. Even if modulations of fo are largely due to adjustments of the intrinsic and extrinsic laryngeal musculature, Ps is one of the factors that influences the rate of vocal fold vibration and therefore some aspects of stress are connected with frequency. An increased Ps automatically triggers an increased rate of fo affecting the baseline of an utterance. How are these variables controlled remains largely unknown.

Results of the experiments presented in this paper show that in addition of Ps rise accompanying stress there is complex pattern of fo. In a declarative sentence stresse on f_o generally shows a falling pattern as displayed in Figures 1, 3 and 4. The level from which this fall starts is generally higher on stressed syllables confirming that there is an effect of Ps on f_o on stressed syllables. However, an important point is to note that the comparison between declarative and interrogatives sentences displaying the same lexical material shows that f_o on stressed syllables can be very different. In the sentences compared in Figure 4 and 5 the initial syllables are stressed as they show an increase in Ps. However f_o is falling as expected in the declarative sentence while it is flat and low at the start of the interrogative sentence. Thus a stressed syllable can either show a falling f_o or a flat f_o depending on the type of sentence. This suggests that, even if there is a small influence of Ps on the rate of vocal folds vibrations, f_o has a different control from Ps.

Claims such as those made by [1] that the f_o falls over the course of an utterance because Ps also declines are not confirmed in our data. Even if at times there are some parallel movements between f_o and Ps contours, the latter remains largely independent of fo. Figure 3 show a clear example of a flat Ps prolonged over three syllables suggesting that speaker deliberately maintains this level to realise a suite of stressed syllables where f_o displays the expected falling pattern on each syllable.

The fact that Ps and f_o have a different control might be a consequence arising from spinal innervation of the respiratory muscles, starting from the region of the cranial nerves 3, 4, 5 and going to the region of lumbar nerve 1 [5] while muscles controlling the laryngeal musculature are only cranial nerves (mainly the cranial nerve 10 the vagus nerve). This has to be explored in future research with more subjects.

5. REFERENCES

[1] Cohen, A., Collier, R., others, 1982. Declination: construct or intrinsic feature of speech pitch? *Phonetica* 39(4-5), 254–273.

[2] Demolin, D. 2007. Phonological universals and the control and regulation of speech production. *Experimental approaches to phonology* 75–92.

[3] Draper, M., Ladefoged, P., Whitteridge, D. 1959. Respiratory muscles in speech. *Journal of Speech & Hearing Research*.

[4] Hart, J., Collier, R., Cohen, A. 2006. *A perceptual study of intonation: an experimental-phonetic approach to speech melody*. Cambridge University Press.

[5] Huber, J., Strathopoulos, E. 2015. Speech breathing across the life span and in disease. *The Handbook of Speech Production* 13.

[6] Kent, R. D., Dembowski, J., Lass, N. J. 1996. The acoustic characteristics of american english. *Principles of experimental phonetics* 185–225.

[7] Ladefoged, P. 1968. Linguistic aspects of respiratory phenomena. *Annals of the New York Academy of Sciences* 155(1), 141–151.

[8] Ohala, J. J. 1990. Respiratory activity in speech. In: *Speech production and speech modelling*. Springer 23–53.