PREGNANCY AND THE SINGING VOICE: REPORTS FROM A CASE STUDY

Filipa M. B. Lã

Department of Communication and Arts, INET-MD, University of Aveiro, Portugal

Johan Sundberg

Department of Speech, Music and Hearing, School of Computer Science and Communication, KTH, Stockholm, Sweden

Filipa Martins Baptista Lã

Universidade de Aveiro

Departamento de Comunicação e Arte

Campus Universitário de Santiago

3810-193 Aveiro

Portugal

E-mail: filipa.la@ua.pt

Tel: +351 234 370200 (ext. 23724)

Fax: +351 234 370868

Acknowledgements:

The authors are indebted to the singer for her generous us participation in this project; Schering Health Care Ltd. & Bayer Portugal, for providing the means to acquire the equipment; and the University of Porto. Preliminary reports have been presented at the 2009 MAVEBA meeting in Florence, Italy and at the 39th Annual symposium Care of the Professional Voice, Philadelphia. A preliminary report was published in the Proceedings of the MAVEBA meeting.

ABSTRACT

Objectives: Significant changes in body tissues occur during pregnancy; however, literature concerning the effects of pregnancy on the voice is sparse, especially concerning the professional classically trained voice.

Hypotheses: Hormonal variations and associated bodily changes during pregnancy affect phonatory conditions, such as vocal fold motility and glottal adduction.

Design: Longitudinal case study with a semi-professional classically trained singer.

Method: Audio, electrolaryngograph, oral pressure and air flow signals were recorded once a week during the last twelve weeks of pregnancy, 48 hours after birth and during the following consecutive eleven weeks. Vocal tasks included diminuendo sequences of the syllable /pae/ sung at various pitches, and performing a Lied. Phonation and collision threshold pressures, normalised amplitude quotient, alpha ratio and the dominance of the voice source fundamental were determined. Concentrations of sex female steroid hormones were measured on three occasions. A listening test of timbral brightness and vocal fatigue was carried.

Results: Results demonstrated significantly elevated concentrations of oestrogen and progesterone during pregnancy, considerably reduced after birth. During pregnancy collision and phonation threshold pressures were high, and normalized amplitude quotient, alpha ratio and dominance of the voice source fundamental suggested elevated glottal adduction. In addition a perceptible decrease of vocal brightness was noted.

Conclusions: The elevated collision and phonation threshold pressures during pregnancy suggest reduced vocal fold motility and increased glottal adduction. These changes are compatible with expected effects of elevated concentrations of oestrogens and progesterone on tissue viscosity and water retention.

INTRODUCTION

It is a well-established fact that the larynx is subject to sex steroid hormonal influence [1-9]. For example, not only the menstrual cycle, but also pregnancy has been reported to be associated with vocal changes as a response to sex steroid hormonal variations [10]. From videoscopic examinations of the larynx, small submucous haemorrhages, redness and swelling were observed during pregnancy, a condition named as "*Laryngopathia gravidarium*" [11]. Women presenting these symptoms have been advised to avoid vocal strain [12].

Several hypotheses have been proposed to explain these vocal symptoms. During pregnancy, especially during its last trimester, concentrations of sex steroid hormones (i.e. oestrogens, progesterone and testosterone) are higher than normal. This can increase water absorption in the Reinke's space leading to a vocal fold oedema and as a consequence voice aperiodicity, lowering of fundamental frequency and uncontrolled timbral changes. Additionally, pregnancy is commonly associated with an increase of gastroesophageal reflux, which has been identified as one of the causes of developing vocal problems [13]. Also the increase in vascularity during pregnancy might cause traumatic injury in the larynx, aggravated by vocal overuse or misuse and excessive strain during pregnancy [14].

Moreover, the distension of the abdominal muscles involved in the breath management can also interfere with the posture and alignment of the body, and with breathing capacity. The voice might sound 'heavier' and feel more difficult to 'support', so it is possible that the singer will try to compensate for these changes by using the muscles of the neck, head, throat, jaw and tongue [15].

For these reasons, singers have been discouraged from singing during pregnancy [15]. However, the literature in this field is sparse and evidence for the association of vocal changes during pregnancy has been mainly based on singers' reports. For example, in 1984 a survey was conducted asking singers who had been pregnant whether they felt changes in their voices during pregnancy, grouping the answers according to the three trimesters of pregnancy. The results showed that 62% of singers did not notice any changes in their voices during the first trimester of pregnancy; 16% reported that their voices had improved during the first trimester of pregnancy; and 22% reported that, due to morning-sickness, the quality of their voices declined. For the second trimester 49% did not feel changes in the quality of their voices; 45% felt that their voices had improved; and 15% that their voices became worse. For the third trimester the majority of singers reported a more positive effect of pregnancy on voice quality (47%); only 26% perceived that their voices became worse, and 26% that their voices did not change [16]. As the majority of the singers reported none or positive effects of pregnancy on their voices, it seems that pregnancy, from the singer's own point of view, does not affect the voice negatively.

Recently, effects of pregnancy on non-singers' speaking voices were examined, comparing maximum phonation time (MPT), voice turbulence index (VTI) and the prevalence of vocal symptoms (e.g. hoarseness, vocal fatigue, and aphonia) in pregnant and post-partum conditions (i.e. 12-24 hours after birth) [17]. The pregnant group presented significant decrease in MPT while for the post-partum condition, an increase in MPT and a decrease in VTI were found. In addition, vocal fatigue seemed more prevalent in the pregnant group, although vocal symptoms did not differ significantly.

Thus, results suggested that pregnancy affects voice production, and that normal voice production is re-established after birth.

Singers rely on highly developed vocal skills and thus even minor vocal difficulties can be extremely distressful [18]. However, the effects of pregnancy on voice production have not been systematically assessed for singers. Thus, there is no formal support for the claim that singers should refrain from singing during pregnancy. The scarce literature on the effects of pregnancy on the singing voice reflects the need for further studies.

Summarizing, previous research has suggested prevalence of vocal changes related to sex steroid hormonal variations. Moreover, similarity has been reported between the response of the cervical and vocal mucosas to variations in concentrations of these hormones [1, 2]. In addition, pregnancy is associated with cervical biomechanical alterations and increased extracellular water retention [11, 19]. Thus, the hypothesis tested here is that the biomechanical properties of the vocal fold vibration, and thus voice quality, are affected during pregnancy. The aims of the current investigation are: (i) to assess the effects of pregnancy on the singing voice with respect to vocal fold motility and glottal adduction; and (ii) to investigate whether effects of pregnancy in the singing voice are perceptible.

METHODS

A longitudinal comparative case study was carried out with a 28 year-old healthy, non-smoker classically trained soprano, during and after pregnancy. Despite of the limitations of case studies, this study design was preferred because it provides systematic and extensive data shedding light on the complex interactions between different factors that may influence the results [20].

The singer was recorded every week, from the 28th week of pregnancy until week 11 after birth, providing a total of 24 recordings: (i) 12 during the last weeks of pregnancy, the *Prae* group of recordings; (ii) one at 48 hours after birth, the *At* recording; and (iii) 11 during the weeks following birth, the *Post* group of recordings. A total of three blood samples was collected: (i) one in the *Prae* condition, at week 29 of pregnancy, i.e. 10 weeks before birth; (ii) one in the *At* condition, i.e. 48 hours after birth; and (iii) one in the *Post* condition, i.e. week 7 after birth. From the three trimesters in which pregnancy is divided, the last one was selected for the *Prae* condition as it presents the highest values of both oestrogens and progesterone [21].

A combination of a Digital Laryngograph Microprocessor and the Glottal Enterprises MS-110 computer interface was used allowing simultaneous recording of four signals: (1) audio and (2) electrolaryngograph signals, recorded by the Laryngograph device; and (3) the flow and (4) the oral pressure signals, recorded by the Glottal Enterprises unit. The latter were collected by means of a Rothenberg flow mask and a pressure transducer attached to a thin plastic tube inserted into the flow mask, such that its end was located inside the subject's lip opening at the corner of the mouth. Each recording was calibrated using the following procedure: (i) the audio channel was calibrated by recording a sine tone, the sound pressure level of which was measured by means of a sound level meter held next to the recording microphone. The sound level value was announced in the recording. The flow and the pressure channels were calibrated using the fan system and pressure calibration device, respectively, both provided by Glottal Enterprises. All these four signals were digitized and sent over a USB contact into a PC provided with the Speech Studio software; thus, audio, electrolaryngograph signal (ELG), subglottal pressure (P_{sub}) and airflow signals were obtained as separate tracks of wav computer files.

Vocal tasks included six renderings of a set of repetitions of the syllable /pae/ sung as diminuendos at pitches A3, E4, B4 and F5, and the performance of a Lied, "Widmung" (Myrthen, Op. 25/1) by R. Schumann.

At the end of each recording session body mass index was measured, defined as the ratio between the weight in kg and the squared body height in cm. MPT was also determined as the maximum time [in s] that the subject was able to count aloud, after the deepest possible inhalation, without taking a breath. Finally, she was asked to fill in a questionnaire rating along a five point scale the perceived degree of swelling and of quality of sleep.

When all recordings were made, a perceptual evaluation of voice quality during and after pregnancy was undertaken with 10 singing teachers and also with the singer herself. At the end of the study an interview was carried out with the singer to assess self-perception of voice quality changes during and after pregnancy. As increased vocal tiredness and loss of vocal brightness were the symptoms most commonly experienced, these two voice quality parameters were chosen for the listening test.

The listening test contained 24 excerpts of the 10 last bars of the Lied, one from each recording made at the *Prae*, *At* and *Post* conditions. In addition 8 replicated stimuli were added. Using the Glue program included in the Soundswell signal workstation software, the stimuli, were recorded in random order. The stimuli were separated by 4 sec long pauses and saved as wav files on a CD. The duration of the entire test was 12 minutes. The listeners were asked to rate, along visual analogue scales, how bright and how tired the voice sounded, the extremes being labelled: extremely tired/bright and not at all tired/bright.

ANALYSES

Due to technical problems, one of the recordings in the *Prae* group had to be discarded, so a total of 20 recordings could be analysed. The four different wav files of the four different signals (i.e. audio, ELG, flow and P_{sub}) were analyzed by means of the SoundSwell workstation software (Swell.ico).

The first vocal task, i.e. the diminuendo sequences of the syllable /pae/, was used for measuring P_{sub}, determined as the oral pressure during the [p] occlusion. P_{sub} measurement was taken from the second syllable in the sequence, since the first peak showed the increasing pressure typically occurring at the start of this exercise. The values obtained for the six renderings of the task were averaged for each of the four pitches. In addition, phonation threshold pressure (PTP) and collision threshold pressure (CTP) were determined, i.e. the lowest pressures producing vocal fold vibration and vocal fold contact, respectively [22]. These pressures have been assumed to reflect vocal fold motility [22, 23]. Therefore, these parameters were chosen to be compared between the last trimester of pregnancy, at birth and post-partum. PTP was calculated as the mean of the lowest pressure that caused phonation and the highest pressure that did not produce phonation, as evidenced by the flow signal. Loss of vocal fold contact decreases the amplitude of the ELG signal considerably; therefore, CTP was calculated as the mean of the lowest pressure that caused vocal fold contact and the highest pressure that failed to produce vocal fold contact. As the Electrolaryngograph system is provided with an automatic gain control, a sudden decrease of ELG amplitude was used as the criterion of loss of vocal fold contact. The threshold values obtained were averaged across the six versions produced on each of the four pitches.

Voice source data were gained for the pitch of A3 (220 Hz) for pregnancy weeks 29 and 30, for the *At* condition, and for weeks 6 and 7 after birth by inverse filtering the flow signal. The analysis was carried out of at least 8 samples of the two or three loudest /pae/ syllables from the diminuendo task. The filtering was performed using the custom made Decap program (Svante Granqvist). In the present application, the program displayed the inverse filtered waveform and its derivative as well as the spectrum before and after the inverse filtering. A ripple-free closed phase and a smoothly falling source spectrum envelope, void of dips and peaks, were used as the criteria for tuning the inverse filters. From the results was calculated the normalized amplitude quotient (NAQ), defined as the ratio between peak-to-peak amplitude and the product of period time and the negative peak of the differentiated flow glottogram. This parameter can give an estimate of glottal abduction/adduction, thus showing the degree of hypofunction/hyperfunction [24].

The 10 last bars of the Lied task were used to obtain long-term average spectrum (LTAS), bandwidth 300 Hz allowing calculation of the alpha ratio, i.e. the ratio between the energy below and above 1 kHz. This ratio thus reflects the mean strengths of the higher as compared with the lower spectrum partials. The equivalent sound level in dB (Leq), i.e., the time average of sound energy in the audio signal, was measured for the same 10 last bars. In addition, the difference in mean LTAS level was determined over the filter bands surrounding mean F0 and those surrounding two times mean F0. This parameter, expressed in dB, was assumed to be related to the level difference between the first and the second voice source spectrum partials $(H1\text{-}H2)_{LTAS}$. This measure should thus vary with type of phonation [25].

BMI, MPT, and perceived degree of swelling and quality of sleep data were plotted as function of week using Microsoft Office Excel. Also the responses to the listening test were analysed using Microsoft Office Excel. The reliability of the results was assessed in terms of the consistency of responses given to the replicated stimuli. Table 1 lists Pearson’s correlation coefficients for the ratings of these stimuli for each listener. The responses of four listeners, marked in the Table 1, who reached a correlation lower than 0.45 were discarded.

Please insert Table 1 about here

RESULTS

The concentration of sex steroid hormones is shown in Figure 1. The concentrations were clearly reduced for the *At* and *Post* conditions. These observations are in agreement with the results of previous research showing that during pregnancy concentrations of both oestrogens and progesterone are significantly elevated, and that progesterone has a dominant role [17].

Please insert Figure 1 about here

The mean P_{sub} data, shown for all pitches in Figure 2, suggest that there were no clear differences between the three conditions.

Please insert Figure 2 about here

Figure 3 shows the PTP and CTP values as function of week number. The PTP values basically followed Titze's equation [23], and the CTP values were, on average, 3.1 cm H_2O higher than the PTP values, which is similar to the difference found by Enflo & Sundberg [22]. This supports the assumption that these data represent reliable information. The CTP showed a week-to-week variation that, by and large, was similar to that of the PTP (see Figure 4), the two thresholds showing a strong correlation (CTP = 1.3857*PTP + 0,5, R^2=0.945). This supports the assumption that CTP and PTP refer to the same phonatory parameter.

Please insert Figures 3 and 4 about here

Figure 5 shows PTP and CTP for the four pitches analysed for *Prae*, *At* and *Post* conditions. The *Prae* and *Post* values represent averages of all recordings made during each of the two conditions. For both PTP and CTP, pregnancy presented the highest values, thus suggesting a decrease of vocal fold motility.

Please insert Figure 5 about here

The results of the LTAS analyses are illustrated in Figure 6. The alpha ratio failed to show any systematic variation over the time period analyzed, even though the first three weeks yielded quite high values and the final weeks before birth yielded quite low values. By contrast, $(H1\text{-}H2)_{LTAS}$ showed clear correlation with week number, correlation coefficients amounting 0.69 and 0.46, for the *Prae* and *Post* conditions, respectively. This parameter presented a deceasing trend towards the week of birth and an increasing trend after birth.

Please insert Figure 6 about here

The inverse filtering analyses showed systematic variation of NAQ as can be seen in Figure 7. The figure shows mean values for the loudest samples of the diminuendo sequences of the syllable /pae/ sung on pitch A3. These values refer to the average of weeks 10 and 11 before birth, to the *At* condition and to the average of weeks 6 and 7 after birth. NAQ showed a considerably greater average for the *Post* than for the *Prae* and *At* conditions. This suggests that the singer sung with less glottal adduction during these weeks after birth.

Please insert Figure 7 about here

Figure 8 shows, as functions of week number, BMI, MPT and the ratings of swelling and quality of sleep. Clear discontinuities can be observed for MPT, BMI, and perceived degree of swelling near birth, the two latter changing in accordance with expectations. MPT was shorter during the *Prae* than the *Post* condition, which agrees with previous results [17]. MPT decreased towards birth and showed a strong correlation with BMI (MPT = 118 - 2.662*BMI, R^2=0.768). Perceived quality of sleep deteriorated clearly during the weeks just before and after birth.

Please insert Figure 8 about here

Some of the parameters analyzed, e.g. $(H1\text{-}H2)_{LTAS}$ and NAQ, showed a systematic variation with conditions, supporting the assumption of perceptible effects. The results of the listening test confirmed this assumption only with regard to the mean ratings of brightness (see Figure 9). Brightness ratings tended to decrease towards birth and to increase after birth, according to both panel and the singer. With regard to tiredness, on the other hand, the panel's mean ratings and the singer's own evaluation failed to show any effect.

Please insert Figure 9 about here

DISCUSSION

Discerning the causality between sex hormones and voice is difficult. An important reason is the complex nature of the interaction between aerodynamic conditions and biomechanical vocal fold properties underlying voice production. This complexity might be further aggravated by the unclear influences of sex steroid hormonal variation and also by great inter-individual variation.

Nevertheless, the results of the present investigation have revealed several changes in voice production and voice quality parameters accompanying this singer's sex steroid hormonal variations during pregnancy. As expected, concentrations of both oestrogens and progesterone were elevated during pregnancy and substantially decreased for the *At* and *Post* conditions. These changes in hormonal content may be relevant to the documented voice changes.

An effect of pregnancy on vocal fold motility was found, both PTP and CTP showing the highest values during the *Prae* condition. Elevated concentrations of oestrogens and progesterone, as it occurs during the last trimester of pregnancy, have been reported to be associated with changes in vocal fold tissue: (i) oestrogens increase vocal fold epithelium thickness; (ii) progesterone leads to changes in the intermediate layer, causing dryness and increased tissue viscosity [14; 2]. Increased dryness and tissue viscosity were found to be associated with an increase of PTP [26, 27]. Thus these two effects possibly underlie the increase in PTP and CTP observed during the last trimester of pregnancy in the present study.

Additionally, during pregnancy there is an increase of solubility of collagen fibres of the cervical stroma making this tissue less resistant and thus more yielding [28]. Taking into account that strong similarities have been found between the response of the cervical and vocal fold mucosas to hormonal variations [1, 2], one might speculate that also the vocal fold collagen fibres solubility might increase during pregnancy. If so, one would expect that due to a less resistant tissue, PTP and CTP would be lower during pregnancy. However this assumption was not supported by the results. Indeed, the opposite effect was observed. Possibly, then, the effect of the viscosity increase may have dominated over that of the increased solubility of collagen fibres. It may be rewarding to measure PTP and CTP during the menstrual cycle, given the associated substantial variations of hormonal concentrations.

$(H1\text{-}H2)_{LTAS}$ reached a minimum at birth and the alpha ratio was found to decrease towards birth, both suggesting stronger adduction. The increase of NAQ after birth supports this same conclusion, since low values of this parameter have been found to reflect elevated degrees of phonatory pressedness [25]. An increase in glottal adduction near birth is likely to require elevated P_{sub}; however, this effect was not observed. On the other hand, one should have in mind that the PTP and CTP shifts were quite small in comparison with the high P_{sub} values used in singing.

According to the listening test, brightness tended to decrease towards birth. This perceptual quality is typically related to the spectral balance, which is reflected in the alpha ratio. However, this ratio was found to decrease during the *Prae* condition, reaching a minimum near birth. This implies that the higher spectrum partials became stronger. However, it is possible that the decreased alpha ratio mainly reflected the reduced amplitude of the voice source fundamental. This is likely to be the case as the fundamental is typically the strongest partial below 1 kHz in female singing at high pitches.

The documented changes of phonatory characteristics mentioned above suggested that the singer was singing with a stronger glottal adduction near birth. It seems reasonable to assume that this would have been perceived as an increase of vocal tiredness, but no such effect was found in the listening test. This is not entirely surprising, since an essential part of a professional singer’s skill must be the ability to produce sound of high timbral quality even under adverse phonatory conditions.

It is important to stress that our results do not allow any conclusions on a causal relationship between the hormonal variations and the variations of voice parameters of our single subject. A set of pre-pregnancy recordings would have been advantageous, but was not feasible. It is possible that the observed vocal changes might have been related also to other factors. For example, the observed increase of both BMI and perceived degree of swelling, and the decrease of both MPT and perceived quality of sleep during pregnancy may very well have contributed to the voice changes noted.

Nevertheless, our strategy was worthwhile since it revealed a number of perceptible and measureable voice changes accompanying changes of hormonal concentrations during pregnancy. In view of the week-to-week variations of vocal parameters, it may be enough in future studies to analyse recordings made only twice a month and to focus on large effects in the first place.

CONCLUSIONS

The present case study verifies our hypothesis that, for this singer, pregnancy reduced vocal fold motility, as shown by increased PTP and CTP. Changes of NAQ, $(H1-H2)_{LTAS}$ and the alpha ratio suggested increased glottal adduction during pregnancy. The results of the listening test indicated perceptible changes in vocal brightness during pregnancy. These findings are compatible with the assumption that pregnancy is associated with increase in tissue viscosity and vocal dryness, conditions previously found to be associated with elevated concentrations of both oestrogens and progesterone.

REFERENCES

1. Abitbol J, Abitbol P & Abitbol B. Sex hormones and the female voice. J Voice, 1999; 13: 424-446.

2. Abitbol J, Brux J, Millot GM, Masson F, Mimoun OL, Pau H & Abitbol B. Does a hormonal vocal cord cycle exist in women? Study of vocal premenstrual syndrome in voice performers by videoscopy-glottography and citology on 38 women. J Voice; 1989; 3: 157-162.

3. Lã FMB, Davidson JW, Ledger W, Howard DM & Jones G. A case-study on the effects of the menstrual cycle and the use of a combined oral contraceptive pill on the performance of a western classical singer: an objective and subjective overview. Musicae Sciencea - Special Issue: Performance Matters, 2007; 85-107.

4. Lã FMB, Ledger W, Davidson JW, Howard DM & Jones G. The effects of a third generation combined oral contraceptive pill on the classical singing voice. J Voice, 2007; 21: 754-761.

5. Lã F & Davidson JW. Investigating the Relationship between Sexual Hormones and Female Western Classical Singing. Res Stud Mus Edu, 2005; 24: 75-87.

6. Amir O, Kishon-Rabin L & Muchnik C. The effect of oral contraceptives on voice: preliminary observations. J Voice, 2002; 16: 267-273.

7. Amir O, Biron-Shental T, Muchnik C & Kishon-Rabin L. Do oral contraceptives improve vocal quality? Limited trial on low-dose formulations. Obstet & Gynecol, 2003; 101: 773-777.

8. Amir O & Biron-Shental R. The impact of hormonal fluctuations on female vocal folds. Curr Opin Otolaryngol Head Neck Surg, 2004; 3: 180-184.

9. Amir O & Kishon-Rabin L. Association between birth control pills and voice quality. Laryngoscope, 2004; 114: 1021-1026.

10. Davies DG & Jahn AF. Care of the Professional Voice: A Management Guide for Singers, Actors and Professional Voice Users. Oxford: Butterworth Heinemann, 1999.

11. van Gelder, L. Psychosomatic aspects of endocrine disorders of the voice. J Comm Disord, 1974; 7: 257-262.

12. Brodnitz FS. Hormones and the human voice. Bull N Y Acad Med, 1971; 47: 183-191.

13. Sataloff RT. The professional voice: Part I. Anatomy, function, and general health. J Voice, 1987; 1: 92-104.

14. Prevelic GM. The effects of sex hormones on the female voice. Musical Performance. 2000; 2: 93-103.

15. Sataloff RT, Emerich KA & Hoover CA. Endocrine Dysfunction. In Sataloff, Ed. Professional Voice: The Science and Art of Clinical Care. 2nd Edition. San Diego: Singular Publishing Group, 1997: 291-297.

16. Abramson AL, Steinberg BM, Gould WJ, Bianco E, Kennedy R & Stock, R. Estrogen receptors in the human larynx: clinical study of the singing voice. In Laurence, Ed. Transcripts of the Thirteenth Symposium: Care of the Professional Voice. Part II. New York: The Voice Foundation, 1984: 409-413.

17. Hamdan AL, Mahfoud L, Sibai A & Seoud M. Effect of Pregnancy on the Speaking Voice, J Voice, 2009; 23 (4): 490-493.

18. Green MCL & Mathieson L. The Voice & Its Disorders. 6th Edition. Philadelphia: Whurr Publishers Ltd, 2001.

19. Garfield RE, Saade G, Buhimschi C, Buhimschi I, Shi L, Shi SQ & Chwalisz K. Control and assessment of the uterus and cervix during pregnancy and labour, Hum Reprod Update, 1998; 4 (5): 673-695.

20. Blaxter L, Dodd K & Itight M. Mature student markets: an institutional case study. Higher Education, 1996; 31 (2): 187-203.

21. Fleming AS, Ruble D, Krieger H & Wong PY. Hormonad and Experiential correlates of maternal responsiveness during pregnancy and the puerperium in human mothers. Hormones and Behavior, 1997; 31: 145-158.

22. Enflo L & Sundberg J. Vocal fold collision threshold pressure: an alternative to phonation threshold pressure? Logoped Phoniatr Vocol, 2009; 34 (4): 210-217.

23. Titzte IR. Phonation threshold pressure: A missing link in glottal aerodynamics. J Acoust Soc Am, 1992; 91: 2926-35.

24. Sundberg J, Thalén M, Alku P & Vilkman E. Estimating perceived phonatory pressedness in singing from flow glottograms, J Voice, 2004; 18: 56-62.

25. Klatt DH & Klatt LC. Analysis, synthesis, and perception of voice quality variations among females and male talkers. J Acoust Soc Am, 1990; 8: 820–857.

26. Verdolini-Marston K, Titze, IR & Druker DG. Changes in Phonation Threshold Pressure with Induced Conditions of Hydration. J Voice, 1990; 4(2): 142-151.

27. Titze, IR Phonation threshold pressure measurement with a semi-occluded vocal tract. J Speech Lang Hear Res, 2009; 52: 1062-1072.

28. Myers K, Socrate S, Tzeranis D & House M. Changes in the biomechanical constituents and morphologic appearance of human cervical stroma during pregnancy. J Obstet Gynecol Reprod Biol. 2009; 144S: S82-S89.