Influence of Menstrual Cycle on Clinical Measures of Voice: A Comparison of Singers and Non Singers

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Introduction

Voice is a marvelous instrument. The importance of the human voice in modern society cannot be overstated. It is the primary instrument through which most of us project our personalities and influence our compatriots. And it is the same instrument through which the art of singing is expressed.

The principles of proper voice production are largely the same in speaking and singing. Infact, many people believe that the singing voice is simply a natural extension of a good speaking voice (Carol & Sataloff, 1991). Singers follow particular strategies to achieve optimum control of the breath, influencing tonal quality, range and dynamics. They use the diaphragmatic muscle support to supply adequate breath pressure to the vocal folds for the sustaining of any desired pitch (Thorpe, Cala, Chapman & Davis, 2001).

However, vocal folds are the ultimate producers of voice. So for the production of good quality voice vocal folds should be intact. There are many factors which affect the vocal folds. One among them is the effect of hormonal variations in females during menstrual cycle (Boon, 1991; Felipa de la & Davidson, 2003).

The menstrual cycle is divided into *follicular phase* (beginning with the menstrual period and ends just prior to ovulation) and *luteal phase* (beginning just after ovulation and ends prior to menstruation) according to Andrews (1999). The female professional voice user may have special problems during the premenstrual period and voice complaints are usually not psychogenic or anxiety related (Benninger, 1994).

Most studies have suggested that the voice changes occur in the premenstrual phase of the menstrual cycle due to edema with subsequent increase in mass of the vocal folds. Edema of the vocal folds may produce voice breaks, difficulty with smooth register transition, breathiness, weakness, an inability to sing certain scales and adequately support tones (Boone, 1991; Bunch, 1982; Chae, Choi, Kanh, Choi & Jin, 2001 and Felipa de la & Davidson, 2003).

Need for the Study

Though voice changes are noticed predominantly in the premenstrual phase it can also be noticed during menstruation (Felipa de la & Davidson, 2003). It has been reported that not all women experience voice changes during their regular menstrual cycle and that voice changes are more readily noticed in singers than in non-singers (Chae, et. al., 2001). According to Silverman, Catherine & Zimmer (1978), premenstrual voice change was supposed to be uncommon in young women with no voice training and the apparent differential effect of the menstrual cycle on trained as opposed to untrained voices deserves systematic investigation.

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Further, (Abitbol, Abitbol & Abitbol, 1999) reported that there would be loss of tone in all striated muscles including abdominal muscular belt and the intercostal muscles resulting in reduced pulmonary air. Majority of such studies were done on western classical singers. Western classical music is different from Indian classical music. Western classical music insists on the use of diaphragm to sing where as Indian music advocate the use of chest and head voice for singing (www.carnatica.net).

Since there is dearth of studies pertaining to the influence of hormonal variations consequent to menstruation in Indian classical singers and non-singers the present study was planned. The study aimed at comparing the acoustic and aerodynamic measures as a factor of menstrual cycle hormonal variations in Indian Carnatic classical singers and non-singers.

Review

"Singing today is an art which is very much alive and growing. Singers are capable of bringing audience to their feet or to tears. They are artists in the truest sense" (Carol & Sataloff 1991). Singing as an art exists in almost all cultures of the world in which traditions of the past and the information of the present can be combined in exciting ways. Singing has a remarkable status in Indian culture. There have been and continue to be voices in Indian music which can stand the test of audience demands in any culture of the world. Carnatic music interestingly is one of the traditional Indian music which has demand all over the world (www.carnatica.net).

According to Callaghan (2000) the voice quality of singers is better when compared to non-singers due to the formal training they undergo. Singers may have superior sensory abilities that help them develop finely tuned control of sub glottal pressure and airflow to meet musical demands. It is training rather than any particular physiological endowment that produces this control.

Thomasson & Sundberg (1991) have reported that professional singers exhibit consistent breathing patterns when repeating the same music a number of times implying that singers follow some optimized pattern. Trained singers have an increased respiratory capacity compared to untrained singers or the normal population (Gould 1977). Experienced singers refer to the importance of abdominal or diaphragmatic muscle "support" for achieving optimal control of the breath influencing tonal quality, range, dynamics and especially projection of the sound. It seems likely that the condition of greater support leads to an increase in sub glottal pressure which together with simultaneous adjustments of the laryngeal musculature gives rise to the continuous glottal flow. The method used to achieve "support" is not independent of the functioning of the vocal folds (Thorpe et al., 2001).

Voice problems related to sex hormones are encountered most commonly in female singers. Although voice changes associated with the normal menstrual cycle may be difficult to quantify there is no question that they occur. The effect of the menstrual cycle on the voice has been an area of much debate and investigation (Silverman, et al. 1978).

Variations in concentrations of hormones during normal menstrual cycle

Familiarity with the normal menstrual cycle and the variation in hormone concentrations is helpful in understanding the effect of menstrual cycle on female voice.

The normal menstrual cycle in females begins with the menstrual period and ends just prior to the next menstrual period. The most frequent length of the cycle is 28 days to about 35 days in apparently normal individuals (Vander, Sherma & Luciano 1952). The menstrual cycle is divided into two phases. The first, *follicular phase* begins with the menstrual period, normally occupies 14 days of the cycle and ends just prior to ovulation. The second, *luteal phase* is the time from ovulation to the onset of next menstruation which normally occupies the next 14 days of the cycle.

The menstrual cycle is regulated by cyclic ovarian hormonal changes. The *follicular phase* is characterized by gradually increasing levels of estrogen and low levels of progesterone. Estrogen reaches its highest level just before ovulation and in the *luteal phase* estrogen decreases in concentration but rises again slightly premenstrually. Progesterone levels increase after ovulation for the first half of the *luteal phase* and then gradually decrease to a lower level (Andrews 1999).

Effect of menstrual cycle on voice related organs

Human vocal cord is a hormonal target organ. It has been reported that the vocal cord estrogen receptors are distributed in the mucosal epithelium and progesterone receptors are present in the intermediate layer (Ferguson, Hudson & McCarty, 1987). Estrogen and progesterone act synergistically on the vocal muscle-mucosal complex and have vascular, hydration, secretary and energetic effects. When the estrogen level is decreased the mucopolysaccharide is degraded into small polymers that combine easily with water to cause submucosal edema (Brodnitz 1971). There is an increase in the production of mucous which modifies the structure of the laryngeal mucosa just before ovulation and consequently the tone of the voice can also be slightly altered (Abitbol, et. al., 1999).

During the premenstrual phase, change in the estrogen concentration also induces vasodilatation, increased vascular permeability, changes in the sol-gel equilibrium state and salt and water retention in the connective tissue of the vocal cord. This leads to an increase in the vocal cord volume resulting in difficulties in high tone phonation (Abitbol 1989).

Davies & Jahn (1998) reported that since female singers rely on abdominal muscle strength for support to a major degree, premenstrual abdominal cramping or bloating was troublesome for singing. A loss of tone in all striated muscles including the vocal muscles, the abdominal muscular belt and the intercostal muscles results in reduced pulmonary power (Abitbol et al. 1999). It has also been reported that the vocal folds become swollen and behave like rigid walls thus resulting in air pressure variations and turbulence in the air stream creating breathy voice and interfering with singing performance (Felipa de la & Davidson 2003).

The premenstrual estrogen-progesterone combined activity causes vasodilatation by relaxing smooth muscles thereby increasing blood volume. These changes result in engorgement of vocal fold blood vessels and results in vocal fold edema. Progesterone increases the viscosity and acidity levels in the secretions of the glandular cells causing dryness of the vocal folds, reduced tonicity of the laryngeal muscles and edema of the vocal folds during the premenstrual period (Abitbol et al. 1999).

Chae et al. (2001) have suggested that ovarian hormones could affect laryngeal behavior through the alterations at neurotransmitter levels. The changes in tone of voice secondary to changes in sex hormone concentrations in the premenstrual phase is thought to be a combined result of physical changes due to vocal cord edema and alterations in vocal cord control system at the neurotransmitter level (Baer 1979). According to Andrews (1999) most of the ill effects were seen in the immediate premenstrual period known as 'Laryngopathia Premenstrualis'. This condition is common and caused by physiologic, anatomic and psychological alterations secondary to endocrine changes. The psychological, physical and vocal effects of premenstrual syndrome reveal wide range of significant effects for a female singer with frequently reported vocal symptom being difficulty in singing high notes. Symptoms occurred with moderate regularity and severity (Davis & Davis, 1993). Most opera companies now have 'grace days' built into their singers' contracts. A few days before their menstruation female vocalists do not sing (Bonne 1991; Davies & Jahn 1998; Silverman et. al., 1978).

Changes in voice during menstrual cycle

According to Boone (1991) a young woman may experience a small amount of hoarseness during her menstrual cycle. Voice complaint during the menstrual cycle is not anxiety-induced or psychogenic; they are caused by the physical changes of the vocal cords. The loss of a note or two at the top of the singing range is well documented in female opera singers at premenstrual times. Davies & Jahn (1998) suggested that the vocal symptoms associated with the premenstrual phase of the menstrual cycle include a loss of high tones, vocal instability and fatigue, decreased vocal efficiency, uncertainty of pitch and huskiness together with reduced vocal power and flexibility. Although premenstrual hormonal changes may be present in the general female population voice change is rare. Singers notice changes in voice more readily than non-singers because they employ a greater voice range and also because occupational vocal cord abuse facilitates changes in vocal cords (Chae et. al., 2001).

Flach, Schwickardi & Simon (1968) in their study on 136 professional singers observed voice changes in 104 singers in the pre and inter menstrual period. Majority of the singers reported voice changes as disadvantageous. Lacina (1968) found that voice changes just before and during menstruation (menstrual dysodia) affected one third of the 100 Opera singers in his study. He reported that the voice change did not occur regularly on one particular day of the premenstrum and was not consistent for each menstrum. Singers complained of menstrual dysodia and variation in voice quality ranging from dull and colourless to racous and hoarse. In some cases hyperemia, edema or even hemorrhage of the vocal cords were noticed. Frequently the tension of the vocal cords was supposed to have reduced which results in a husky timbre. It was also possible that forced singing could cause small haematomas of the vocal cords to some extent (Von Gelder 1974).

Silverman et al., (1978) analyzed the spectrum of the sustained productions of three vowels /a/, /i/, /u/ produced by 20 undergraduates with no vocal training at ovulation and at premenstruation and were rated for degree of hoarseness. Statistical analysis of the data indicated that the typical subject was no hoarser during premenstruation than at ovulation. Thus he found that premenstrual hoarseness is a rarely occurring condition among young women with no vocal training.

Flach, Shwickardi & Heidelbach (1980) reported that menstruation can exert a negative influence on the voice in female singers. There were however no significant correlation between the menstrually determined changes of voice and the course of menstruation. There was no consistent pattern in an individual from month to month but the general premenstrual buildup of fluid can affect the vocal folds so that they swell and the voice sounds tired and hoarse and has diminished power and flexibility.

Abitbol et al. (1989) studied 38 women during the ovulation and premenstrual phases of two monthly cycles. They found that estrogen-progesterone level alterations associated with these cycles caused laryngeal water retention, edema of the interstitial tissue and venous dilatation resulting in vocal hoarseness and vocal fatigue in 22 of the 38 female vocal performers (Classical, Jazz, Vocal teachers and actors). They also found that the subjects had decreased vocal range, vocal fatigue, diminished vocal power and flat, colorless timbre during the premenstrual phase.

Abitbol et al., (1999) did a study on 77 female vocal professionals presenting with a premenstrual dysphonia. They found that 33% of the women exhibited symptoms like vocal fatigue, decreased range with a loss of pianissimo, diminished vocal power and flat and colorless timber during their premenstrual phase.

Chae et al., (2001) evaluated the relationship between voice change and premenstrual syndrome (PMS) by comparing acoustic measurements using Dr. Speech Science program. Phonation of /a/ for 5 seconds was recorded at the mid follicular phase of the menstrual cycle and then 2-3 days before menstruation. A total of 28 female non-singers with equal number of PMS-positive and PMS-negative grouping formed the subjects. They found that there was no significant difference in the acoustic parameters between the two phases in all subjects. In PMS-positive group 'Jitter' was significantly increased during the premenstrual phase compared to the follicular phase. The patients' PMS score was not correlated with the severity of voice change. They concluded that the changes in the voice parameters were objectively identified in the PMS- positive group.

A study done to investigate the influence of sexual hormones on menstrual cycle in the operatic singing voice concluded that differences in the fundamental frequency and vocal breathiness were less significant for singers who were taking the contraceptive pill than for those who were not pill takers. This is because contraceptive pill avoids hormonal level variations during the cycle as it provides the same amount of estrogen and progesterone throughout the menstrual cycle (Felipa de la & Davidson 2003).

A review of literature suggests that there are acoustic and aerodynamic changes in the voice during menstrual cycle due to the influence of variations in hormonal balance. According to few authors premenstrual voice change was supposed to be uncommon in young women with no voice training.. Also premenstrual voice changes were more commonly seen in singers when compared to non-singers.

Aims of the study

The aims of the study were as follows:

i To compare and correlate the acoustic parameters of voice across singers and non-singers during different phases (follicular and luteal) of menstrual cycle.

ii To compare and correlate the aerodynamic parameter (vital capacity) across singers and non-singers during different phases of menstrual cycle.

Method

The present study aimed to compare and correlate the acoustic and aerodynamic parameters of voice across singers and non-singers during different phases of menstrual cycle.

Subjects

Ten female Carnatic classical singers and 10 female non-singers who did not have any kind of vocal training were considered as subjects for the study. All the subjects ranged in age from 20 to 27 years with a mean age of 23.5 years.

Selection criteria for 'Singers'

i Should be pursuing/have passed senior level in Carnatic vocal music
ii Should have no complaints of voice, hearing or any other medical problems

iii Should have regular menstrual cycle

iv Should not be users of any hormone or related medicines

Selection criteria for 'Non-singers'

v Should not have undergone any kind of vocal training.

vi Should have met the above mentioned criteria from (ii) to (iv)

Procedure

Voice sample recording and vital capacity measurements were done at two phases of the menstrual cycle, that is, once each during luteal and follicualr phases.

Phase 1 *(Premenstrual stage of Luteal phase):* Between day 25 to 28 of the menstrual cycle.

Phase 2 *(Post menstrual stage of Follicular phase):* Between day 11 to 13 of the menstrual cycle.

Task

1. ***Phonation***: The subjects were instructed to phonate vowels |a|, |i| and |u| at comfortable pitch and loudness for a maximum of 5 seconds. The sample was audio-recorded using Sony digital portable mini-disc tape recorder, Model MZ-R 30 with external Aiwa microphone. The microphone was positioned at a distance of about 4 inches from subject's mouth during recording.

2. ***Vital capacity***: Vital capacity is the amount of air that can be exhaled after a deep inhalation. The portable hand held Vitalograph, Model 2120 was used to measure the vital capacity. Subjects were instructed to take a deep breath and blow the inhaled air in to the disposable mouthpiece of the Vitalograph. The values of vital capacity displayed on the screen of the Vitalograph were noted in liters and average of three trials was considered for each subject.

Analysis of the voice sample

The audio recorded samples of the two subject groups were subjected to acoustical analysis using MDVP software of CSL-4500 of Kay Elemetrics, New Jersey. The calculation algorithms for each parameter were preset and the frame of analysis was set for sustained phonation. The initial and final parts of the vowels were eliminated, capturing the middle 3 second sample for analysis. This was done to avoid voice onset and offset recording error. The following acoustic measures were extracted after MDVP analysis:

I Fundamental frequency information measures

1. Average fundamental frequency (F_0)
2. Average pitch period (T_0)
3. Highest fundamental frequency (Fhi)
4. Lowest fundamental frequency (Flo)
5. Standard deviation of frequency (STD)

II Short and long term frequency perturbation measures

1. Absolute jitter (Jita)
2. Jitter percent (Jitt)
3. Relative average perturbation (RAP)
4. Pitch perturbation quotient (PPQ)
5. Smoothed Pitch perturbation quotient (sPPQ)
6. Fundamental frequency Variation (vF_0)

III Short and long term amplitude perturbation measures

1. Shimmer in dB (ShdB)
2. Shimmer percent (Shim)
3. Amplitude perturbation quotient (Apq)
4. Smoothed Amplitude perturbation quotient (sAPQ)
5. Peak-Amplitude Variation (vAm)

IV Voice break related measures

1. Degree of voice breaks (DVB)
2. Number of voice breaks (NVB)

V Sub-harmonic related measures

1. Degree of sub harmonic segments (DSH)
2. Number of sub harmonic segments (NSH)

VI Voice irregularity related measures

1. Degree of Voice less (DUV)
2. Number of unvoiced segments (NUV)

VII Noise related measures

1. Noise to harmonic ratio (NHR)
2. Voice turbulence index (VTI)
3. Soft phonation index (SPI)

VIII Tremor related measures

1. F_0 tremor intensity index (FTRI)
2. Amplitude Tremor intensity index (ATRI)
3. F_0 tremor frequency (Fftr)
4. Amplitude tremor frequency (Fatr)

Statistical analysis

SPSS version 10 was used for statistical analysis of the acoustic and aerodynamic data. Descriptive statistics and independent samples 't' for significance were extracted for the data.

Results

The present study aimed to find the changes in voice characteristics in singers and non-singers across different phases of menstrual cycle. The data was subjected to statistical analysis using SPSS software version 10. Results are presented in table 1.

Note: The means of parameters of Sub Harmonic Component related measures, Voice irregularity related measures and Voice beak related measures were zero and hence are not depicted in the table. When singers were compared across the two phases as depicted in Table-1, increased mean values were noticed for F_0 related parameters–Fhi and Flo for /a/ phonation; F_0 and Flo for /i/ and /u/ phonation during phase2 of menstruation. Short and long term frequency perturbation measures–Jita, Jitt and sPPQ had increased mean values for phonation of /a/; Jita, Jitt, RAP, APQ, sPPQ for phonation of /i/ and Jitt for phonation of /u/ during phase 2.

Table1: Mean, SD and t values for phonation of |a|, |i|, |u| in singers in phase1 & 2

Parameter		|a|			|i|			|u|		
		Mean	Std	t value	Mean	Std	t value	Mean	Std	t value
F_0	Phase1	256.87	35.36	0.04	259.75	36.27	0.13	260.15	36.09	0.24
	Phase2	256.17	35.04		261.78	35.78		264.06	35.47	
T_0	Phase1	3.95	0.52	0.02	3.91	0.52	0.14	3.92	0.55	0.3
	Phase2	3.95	0.51		3.88	0.52		3.85	0.52	
Fhi	Phase1	278.55	32.11	0.84	286.03	30.52	0.22	301.66	55.49	0.79
	Phase2	295.6	55.5		282.39	43.33		283.92	43.67	
Flo	Phase1	215.72	39.85	0.75	234.43	48.61	0.6	207.81	55.6	0.85
	Phase2	228.17	34.13		245.23	29.63		228.99	56	
STD	Phase1	3.96	2.13	0.46	3.75	1.52	0.02	11.04	16.79	0.59
	Phase2	3.53	2.06		3.75	1.32		7.06	12.7	
Fftr	Phase1	4.66	2.89	0.98	4.02	1.31	0.57	4.7	2.86	1.33
	Phase2	3.63	1.29		3.69	0.98		3.35	0.84	
Fatr	Phase1	5.8	2.77	1.29	3.44	0.911	0.91	4.02	0.91	0.49
	Phase2	4.35	1.55		3.91	1.25		4.5	2.4	
Jita	Phase1	24.05	15.31	1.04	39.97	26.47	0.83	68.25	55.1	1.83
	Phase2	30.81	13.63		47.88	14.15		35.25	15.16	
Jitt	Phase1	0.6	0.57	0.03	1.1	0.52	0.73	1.73	1.54	1.65
	Phase2	0.8	0.44		1.25	0.4		0.91	0.37	
RAP	Phase1	0.48	0.35	0.02	0.65	0.31	0.89	1.03	0.92	1.57
	Phase2	0.47	0.27		0.76	0.24		0.56	0.23	
PPQ	Phase1	0.46	0.33	0.07	0.63	0.29	0.79	1.02	0.88	1.63
	Phase2	0.46	0.25		0.72	0.23		0.54	0.24	
sPPQ	Phase1	0.53	0.32	0.08	0.66	0.26	1.137	1.14	1.04	0.14
	Phase2	0.54	0.25		0.77	0.18		1.06	1.67	
v F_0	Phase1	1.57	0.94	0.65	1.49	0.72	0.31	4.61	7.75	0.56
	Phase2	1.34	0.65		1.41	0.34		2.92	5.68	
ShdB	Phase1	0.23	9.71	0.08	0.13	4.2	0.11	0.33	0.28	0.4
	Phase2	0.22	8.04		0.13	3.7		0.28	0.27	
Shim	Phase1	2.55	1.11	0.14	1.41	0.46	0.18	3.4	3.04	0.36
	Phase2	2.49	0.89		1.44	0.34		2.95	2.86	
Apq	Phase1	1.88	0.86	0.11	1.08	0.39	0.15	2.52	2.16	0.39
	Phase2	1.92	0.71		1.1	0.27		2.17	1.89	
sAPQ	Phase1	3.33	1.86	0.55	2.16	0.66	1.34	3.78	2.37	0.47
	Phase2	3.73	1.31		2.69	1.07		4.43	3.74	
vAm	Phase1	15.44	8.89	0.07	11.34	4.09	0.33	15.45	6.77	0.18
	Phase2	15.17	7.2		10.46	7.48		16.29	13.36	
NHR	Phase1	0.1	3.86	0.16	9.3	2.95	0.21	0.12	6.98	0
	Phase2	0.1	1.17		9.6	3.53		0.12	7.32	
VTI	Phase1	2.73	1.49	0.47	1.6	9.66	1.08	1.9	8.77	0.17
	Phase2		1.33		2.1	1.1		1.8	1.69	
SPI	Phase1	20.88	7.39	0.97	27.68	14.64	0.92	85.49	36.25	0.83
	Phase2	26.02	14.98		33.64	14.31		98.91	36.09	
FTRI	Phase1	0.26	0.12	0.32	0.23	9.55	0.45	0.23	0.1	0.33
	Phase2	0.24	0.12		0.25	0.15		0.25	0.18	
ATRI	Phase1	5.62	4.13	0.67	2.3	1.39	0.77	4.06	3.25	0.01
	Phase2	4.35	3.49		3.17	3.24		4.08	4.78	

Table 2: Mean, SD and t values for phonation of | a|, | i |, | u | in non-singers in phase 1 & 2.

Parameter		| a |			| i |			| u |		
		Mean	SD	t value	Mean	SD	t value	Mean	SD	t value
F_0	Phase1	218.84	22.07	0.1	223.23	16.98		232.61	33.85	.06
	Phase2	217.89	22.62		226.62	16.21	.46	231.84	16.75	
T_0	Phase1	4.61	0.47	0.1	4.5	0.36		4.37	0.55	.20
	Phase2	4.63	0.49		4.43	0.33	.46	4.33	0.33	
Fhi	Phase1	260.36	28.2	0.59	249.64	23.84		272.05	46.18	.37
	Phase2	272.13	55.97		251.54	21.59	.18	264.63	41.84	
Flo	Phase1	193.68	22.94	0.24	204.35	18.27		199.26	23.2	.16
	Phase2	191.19	23.16		209.42	16.94	.64	201.07	26.94	
STD	Phase1	4.11	1.27	0.98	4.17	1.74		8.17	13.46	.92
	Phase2	5	2.55		3.62	1.27	.8	4.18	1.83	
Fftr	Phase1	3.95	1	0.1	3.81	1.86		5.07	3.44	1.11
	Phase2	4.03	1.95		3.91	1.58	.12	3.75	0.94	
Fatr	Phase1	3.58	1.08	0.28	3.55	1.33		3.06	0.82	2.23
	Phase2	3.79	2.09		2.95	1.61	.81	4.1	1.02	
Jita	Phase1	40.56	22.11	0.48	64.87	31.48		54.39	27.26	.74
	Phase2	45.44	23.7		55.27	30.44	.69	65.92	40.4	
Jitt	Phase1	0.87	0.47	0.73	1.45	0.76		1.28	0.75	.59
	Phase2	1.03	0.5		1.24	0.7	.64	1.5	0.89	
RAP	Phase1	0.52	0.29	0.67	0.88	0.46	.65	0.77	0.45	.66
	Phase2	0.62	0.31		0.75	0.43		0.92	0.54	
PPQ	Phase1	0.49	0.27	0.73	0.81	0.41	.59	0.72	0.41	.49
	Phase2	0.59	0.29		0.71	0.4		0.82	0.49	
sPPQ	Phase1	0.55	0.26	0.99	0.84	0.37	.42	0.74	0.38	.60
	Phase2	0.67	0.27		0.77	0.4		0.87	0.51	
VF0	Phase1	1.91	0.66	0.92	1.86	0.73	.91	3.07	4.13	.94
	Phase2	2.25	0.99		1.6	0.54		1.81	0.79	
ShdB	Phase1	0.35	0.11	0.05	0.23	0.11	.75	0.33	0.21	.17
	Phase2	0.35	0.11		0.2	6.65		0.32	0.12	
Shim	Phase1	3.91	1.22	0.02	2.52	1.28	.78	3.62	2.26	.09
	Phase2	3.92	1.6		2.15	0.76		3.54	1.33	
	Phase1	2.97	0.91	0.03	1.78	0.75	.92	2.64	1.53	.34
APQ	Phase2	2.99	1.19		1.51	0.49		2.44	0.88	
	Phase1	4.74	1.2	0.38	3.63	1.33	1.29	4.16	1.91	.03
sAPQ	Phase2	5.02	12.02		2.96	0.95		4.13	1.58	
vAm	Phase1	13.91	15.76	0.18	11.62	3.98	.79	12.04	4.67	.56
	Phase2	14.33	4.43		10.4	2.75		10.98	3.63	
NHR	Phase1	0.11	1.9	1.13	0.11	3.31	1.68	0.14	3.65	.44
	Phase2	0.23	0.31		8.8	2.78		0.13	2.13	
VTI	Phase1	3.3	1.25	1.6	2.2	9.19	1.97	2.1	1.52	.16
	Phase2	2.4	1.26		1.2	1.32		2.2	1.13	
	Phase1	26.82	19.43	0.58	39.89	20.23	.1.65	102.96	42.99	.25
SPI	Phase2	22.92	8.5		55.57	22.03		108.36	51.8	
	Phase1	0.31	0.15	0.86	0.3	0.1		0.29	0.18	.09
FTRI	Phase2	0.37	0.12		0.27	0.25	.25	0.3	0.1	
ATRI	Phase1	3.34	1.82	0.39	3.21	1.62		2.03	1.09	.73
	Phase2	3.69	12.01		2.42	1.21	1.09	2.56	1.72	

Amplitude perturbation measures showed high mean values for the parameters – APQ, sAPQ for /a/; Shim, APQ and sAPQ for /i/ and sAPQ and vAm for /u/ during phase 2 of menstruation. Noise related measures showed high mean values for parameters VTI and SPI for phonation of /a/; NHR, VTI and SPI for the phonation of /i/; NHR and SPI for phonation of /u/. Greater mean values were obtained for tremor related measures – Fatr for /a/; fatr, FTRI and ATRI for /i/ and /u/ during Phase 2. Statistical significance was not observed for any these parameters in singers.

Note: The means of parameters of Sub Harmonic Component related measures, Voice irregularity related measures and Voice beak related measures were zero and hence not depicted in the table

Table-2 depicts comparison for non-singers across the two phases of menstrual cycle. Higher mean values for F_0 related parameters - T_0, Fhi and STD for phonation of /a/; F_0, Fhi and Flo for phonation of /i/ and Flo for phonation of /u/ in phase2. Increased mean were noticed for Short and long term frequency perturbation measures–Jita, Jitt, RAP, PPQ, sPPQ, vF_0 for phonation of /a/; Jita, Jitt, RAP, PPQ, sPPQ for phonation of /u/ in phase2 but the same were reduced for phonation of /i/.

Short and long term average amplitude perturbation measures showed increased mean values for Shim, APQ, sAPQ and vAm for phonation of /a/ in phase2 whereas these measures were decreased for phonation of /i/ and /u/.

Noise related measures showed increased mean values for NHR for the phonation of /a/, NHR and SPI for the phonation of /i/ and VTI and SPI for the phonation of /u/ in phase 2. Tremor related measure showed increased mean values for Fftr, Fatr, FTRI and AFTRI for the phonation of /a/; Fftr for the phonation of /i/ and Fatr, FTRI, and ATRI for the phonation of /u/ in phase 2.

Note: The means of parameters of Sub Harmonic Component related measures, Voice irregularity related measures and Voice beak related measures were zero and hence not depicted in the table

The singers and non-singers were compared during phase 1 and the results are depicted in Table-3. It was noticed that F_0 related parameters - F_0, Fhi, Flo for the phonation of /a/; F_0, Fhi, Flo, for the phonation of /i/ and F_0, Fli, Flo, and STD for the phonation of /u/ revealed greater mean values in singers compared to non-singers.

Short and long term frequency perturbation measures - Jita, Jitt, RAP, PPQ, sPPQ, and vF_0 showed increased mean values for the phonation of /i/ in singers. Short and long-term average amplitude perturbation measures showed increased mean values for vAm for the phonation of /a/; vAm and ShdB for the phonation of /u/ in singers.

Noise related measures showed increased mean value for all the three vowels in non-singers except NHR which was decreased for vowel /i/. Tremor related measurements showed increased mean value for Fftr, Fatr, and ATRI for the phonation of /a/; Fftr for the phonation of /i/; Fatr, and ATRI for the phonation of /u/ in singers.

From Table-3 it can be summarized that for phonation of |a|, F_0, T_0, Shim, Apq were significantly different at .01 level and Fatr, ShdB at .05 level. For the phonation of |i|, F_0, T_0, Fhi, Shim and Apq were significantly different at .01 level and ShdB at .05 level. For the phonation of |u| Fatr was significantly different at .05 level.

Note: The means of parameters of Sub Harmonic Component related measures, Voice irregularity related measures and Voice beak related measures are zero and hence not depicted in the table.

Table-4 shows increased mean values for F_0 related parameters – F_0, Fhi, Flo for the phonation of /a/; F_0, Fhi, Flo, STD for the phonation of /i/ and /u/ in singers.

Table 3: Mean, SD & t values for phonation of |a|, |i|, |u| for singers and non-singers in phase 1

Parameter		|a|			|i|			|u|		
		Mean	Std	t value	Mean	Std	t value	Mean	Std	t value
Fo	Sing	256.87	35.36	2.88	259.75	36.27	2.88	260.15	36.09	1.76
	Non-sing	218.84	22.07		223.23	16.98		232.61	33.85	
T0	Sing	3.95	0.52	2.93	3.91	0.52	2.92	3.92	0.55	1.84
	Non-sing	4.61	0.47		4.5	0.36		4.37	0.55	
Fhi	Sing	278.55	32.11	1.34	286.03	30.52	2.97	301.66	55.49	1.29
	Non-sing	260.36	28.2		249.64	23.84		272.05	46.18	
Flo	Sing	215.72	39.85	1.51	234.43	48.61	1.83	207.81	55.6	0.44
	Non-sing	193.68	22.94		204.35	18.27		199.26	23.2	
STD	Sing	3.96	2.13	0.18	3.75	1.52	0.57	11.04	16.79	0.41
	Non-sing	4.11	1.27		4.17	1.74		8.17	13.46	
Fftr	Sing	4.66	2.89	0.7	4.02	1.31	0.27	4.7	2.86	0.19
	Non-sing	3.95	1		3.81	1.86		5.07	3.44	
Fatr	Sing	5.8	2.77	2.23	3.44	0.911	0.2	4.02	0.91	2.14
	Non-sing	3.58	1.08		3.55	1.33		3.06	0.82	
Jita	Sing	24.05	15.31	1.94	39.97	26.47	1.91	68.25	55.1	0.71
	Non-sing	40.56	22.11		64.87	31.48		54.39	27.26	
Jitt	Sing	0.6	0.57	0.26	1.1	0.52	1.20	1.73	1.54	0.84
	Non-sing	0.87	0.47		1.45	0.76		1.28	0.75	
RAP	Sing	0.48	0.35	0.28	0.65	0.31	1.27	1.03	0.92	0.81
	Non-sing	0.52	0.29		0.88	0.46		0.77	0.45	
PPQ	Sing	0.46	0.33	0.18	0.63	0.29	1.16	1.02	0.88	0.97
	Non-sing	0.49	0.27		0.81	0.41		0.72	0.41	
sPPQ	Sing	0.53	0.32	0.11	0.66	0.26	1.26	1.14	1.04	1.12
	Non-sing	0.55	0.26		0.84	0.37		0.74	0.38	
vFo	Sing	1.57	0.94	0.91	1.49	0.72	1.15	4.61	7.75	0.55
	Non-sing	1.91	0.66		1.86	0.73		3.07	4.13	
ShdB	Sing	0.23	9.71	2.52	0.13	4.2	2.45	0.33	0.28	0.03
	Non-sing	0.35	0.11		0.23	0.11		0.33	0.21	
Shim	Sing	2.55	1.11	2.57	1.41	0.46	2.58	3.4	3.04	0.15
	Non-sing	3.91	1.22		2.52	1.28		3.62	2.26	
Apq	Sing	1.88	0.86	2.73	1.08	0.39	2.60	2.52	2.16	0.13
	Non-sing	2.97	0.91		1.78	0.75		2.64	1.53	
	Sing	3.33	1.86	1.99	2.16	0.66	3.11	3.78	2.37	0.39
sAPQ	Non-sing	4.74	1.2		3.63	1.33		4.16	1.91	
vAm	Sing	15.44	8.89	0.45	11.34	4.09	0.16	15.45	6.77	1.31
	Non-sing	13.91	15.76		11.62	3.98		12.04	4.67	
NHR	Sing	0.1	3.86	0.80	9.3	2.95	1.28	0.12	6.98	0.40
	Non-sing	0.11	1.9		0.11	3.31		0.14	3.65	
VTI	Sing	2.7	1.49	0.97	1.6	9.66	1.42	1.9	8.77	0.36
	Non-sing	3.3	1.25		2.2	9.19		2.1	1.52	
SPI	Sing	20.88	7.39	0.90	27.68	14.64	1.54	85.49	36.25	0.98
	Non-sing	26.82	19.43		39.89	20.23		102.96	42.99	
FTRI	Sing	0.26	0.12	0.72	0.23	9.55	1.56	0.23	0.1	0.89
	Non-sing	0.31	0.15		0.3	0.1		0.29	0.18	
ATRI	Sing	5.62	4.13	1.50	2.3	1.39	1.27	4.06	3.25	1.66
	Non-sing	3.34	1.82		3.21	1.62		2.03	1.09	

Table 4: Mean, SD & t values for phonation of |a|, |i|, |u| for singers & non-singers in phase 2

Parameter		|a|			|i|			|u|		
		Mean	Std	t value	Mean	Std	t value	Mean	Std	t value
F_0	Sing	256.17	35.04	2.90	261.78	35.78	2.83	264.06	35.47	2.59
	Non-sing	217.89	22.62		226.62	16.21		231.84	16.75	
T_0	Sing	3.95	0.51	2.98	3.88	0.52	2.82	3.85	0.52	2.46
	Non-sing	4.63	0.49		4.43	0.33		4.33	0.33	
Fhi	Sing	295.6	55.5	0.94	282.39	43.33	2.01	283.92	43.67	1.0
	Non-sing	272.13	55.97		251.54	21.59		264.63	41.84	
Flo	Sing	228.17	34.13	2.83	245.23	29.63	3.31	228.99	56	1.42
	Non-sing	191.19	23.16		209.42	16.94		201.07	26.94	
STD	Sing	3.53	2.06	1.41	3.75	1.32	0.23	7.06	12.7	0.71
	Non-sing	5	2.55		3.62	1.27		4.18	1.83	
Fftr	Sing	3.63	1.29	0.48	3.69	0.98	0.33	3.35	0.84	0.91
	Non-sing	4.03	1.95		3.91	1.58		3.75	0.94	
Fatr	Sing	4.35	1.55	0.61	3.91	1.25	1.34	4.5	2.4	0.43
	Non-sing	3.79	2.09		2.95	1.61		4.1	1.02	
Jita	Sing	30.81	13.63	1.69	47.88	14.15	0.69	35.25	15.16	2.24
	Non-sing	45.44	23.7		55.27	30.44		65.92	40.4	
Jitt	Sing	0.8	0.44	1.06	1.25	0.4	0.04	0.91	0.37	1.92
	Non-sing	1.03	0.5		1.24	0.7		1.5	0.89	
RAP	Sing	0.47	0.27	1.04	0.76	0.24	0.10	0.56	0.23	1.92
	Non-sing	0.62	0.31		0.75	0.43		0.92	0.54	
PPQ	Sing	0.46	0.25	1.04	0.72	0.23	0.11	0.54	0.24	1.55
	Non-sing	0.59	0.29		0.71	0.4		0.82	0.49	
sPPQ	Sing	0.54	0.25	1.04	0.77	0.18	0.05	1.06	1.67	0.34
	Non-sing	0.67	0.27		0.77	0.4		0.87	0.51	
vF_0	Sing	1.34	0.65	2.43	1.41	0.34	0.92	2.92	5.68	0.61
	Non-sing	2.25	0.99		1.6	0.54		1.81	0.79	
ShdB	Sing	0.22	8.04	2.38	0.13	3.7	2.78	0.28	0.27	0.42
	Non-sing	0.35	0.11		0.2	6.65		0.32	0.12	
Shim	Sing	2.49	0.89	2.46	1.44	0.34	2.68	2.95	2.86	0.58
	Non-sing	3.92	1.6		2.15	0.76		3.54	1.33	
Apq	Sing	1.92	0.71	2.39	1.1	0.27	2.34	2.17	1.89	0.41
	Non-sing	2.99	1.19		1.51	0.49		2.44	0.88	
sAPQ	Sing	3.73	1.31	1.69	2.69	1.07	0.58	4.43	3.74	0.23
	Non-sing	5.02	12.02		2.96	0.95		4.13	1.58	
vAm	Sing	15.17	7.2	0.31	10.46	7.48	0.02	16.29	13.36	1.21
	Non-sing	14.33	4.43		10.4	2.75		10.98	3.63	
NHR	Sing	0.1	1.17	1.22	9.6	3.53	0.56	0.12	7.32	0.16
	Non-sing	0.23	0.31		8.8	2.78		0.13	2.13	
VTI	Sing	2.7	1.49	1.03	1.6	9.66	1.65	1.9	8.77	0.62
	Non-sing	2.4	1.26		1.2	1.32		2.2	1.13	
SPI	Sing	26.02	14.98	0.57	33.64	14.31	2.64	98.91	36.09	0.47
	Non-sing	22.92	8.5		55.57	22.03		108.36	51.8	
FTRI	Sing	0.24	0.12	2.07	0.25	0.15	0.22	0.25	0.18	0.63
	Non-sing	0.37	0.12		0.27	0.25		0.3	0.1	
ATRI	Sing	4.35	3.49	0.48	3.17	3.24	0.620	4.08	4.78	0.84
	Non-sing	3.69	12.01		2.42	1.21		2.56	1.72	

Short and long term frequency perturbation measures showed increased mean values for Jitt, RAP, PPQ, sPPQ for phonation of /i/; and sPPQ and v F_0 for phonation of /u/ in singers but the remaining parameters showed higher mean values for non-singers. Short and long-term average amplitude perturbation measures showed increased mean value for vAm for phonation of /a/ and /i/, sAPQ and vAm for phonation of /u/ in singers.

Noise related measures showed increased mean value for VTI and SPI for the phonation of /a/; NHR and VTI for /i/ in singers. Tremors related measurements showed increased mean values for Fatr and ATRI for the phonation of /a/, /i/ and /u/ in singers.

In summary Table 4 reveals that for |a|, F_0, T_0, Flo are significantly different at .01 level and v F_0, ShdB, Shim, Apq and FTRI at .05 level. For |i|, parameters: F_0, T_0, Flo, ShdB, Shim and VTI are significantly different at .01 level and Fhi and Apq at .05 level. For |u|, F_0 is significantly different at .01 level and parameters Jita and T_0 are significantly different at .05 level.

Table 5: Mean SDs & t value for vital capacity in phase 1 and 2 in singers & non singers.

		Mean	SD	t value
Singers	Phase 1	2.1	0.31	1.45
	Phase 2	2.3	0.27	
Non singers	Phase 1	2.3	0.34	0.28
	Phase 2	2.3	0.29	

Table-5 shows the comparison of mean, SD and t value of vital capacity between phase 1 and phase 2 in both singers and non singers. From the above table, it can be evidenced that the vital capacity is relatively less in both singers and non-singers in phase 1 when compared to Phase 2 though it is not significant.

Table 6: Comparison of vital capacity between singers and non-singers in phase 1 and 2.

Phase	Groups	Mean	SD	t value
Phase 1	Singers	2.1	0.31	0.81
	Non-singers	2.3	0.34	
Phase 2	Singers	2.3	0.27	0.24
	Non-singers	2.3	0.29	

A comparison of mean, SD and t value between singers and non-singers across the two phases is summarized in Table-6. During phase 1 the mean vital capacity for singers is lower than that of non-singers and during phase 2 it is almost the same as non-singers. Also, statistical significance is absent.

Discussion

Acoustic measures

The results of the present study indicated that there was no significant difference for the acoustic parameters in singers across the two phases of menstrual cycle. But Abitbol et al., (1989) and Chae et al. (2001) found changes in singers' voice during premenstrual period.

In non-singers only Fatr was significantly higher for phonation of /u/ during phase 2. This indicates that voice changes in non-singers were not evident across the two phases of menstrual cycle. Support could be drawn from Silverman et al., (1978) and Chae et al., (2000) who reported that no significant difference exists in voice parameters of non-singers across the two phases.

When singers and non-singers were compared in phase 1 and phase 2 individually it was found that singers revealed significant increase in mean values for some of the F_0 related measures in both phases. However in non-singers the mean values for most of the short and long term- frequency and amplitude perturbation measures, noise related measures and tremor related measures were significantly greater. This could indicate that the voice quality was better in singers when compared to non-singers in both the phases. It has been reported that the voice quality of singers is better than non-singers due to the formal training they undergo (Callaghan 2002).

Vital capacity measures

From the results it can be inferred that the vital capacity was relatively less in both singers and non-singers in phase1 than phase 2 confirming the findings of Abitbol et al., (1999) who reported reduced pulmonary power during the premenstrual phase. Further, the results also show that during phase 2 the vital capacity of singers and non-singers was almost the same but in phase1 the vital capacity of singers is lower than in non-singers. Factors related to height and other external factors could be speculated for the lower vital capacity in singers.

The results of the present study cannot be generalized across singers and non- singers as the sample size are less. Further, voice changes due to hormonal variations during menstrual cycle have not been confirmed decisively as there are contradictory reports in literature. Bunch (1982) has reported that not all women experience voice changes during their regular menstrual cycle. Boone (1991) and Davies & Jahn (1998) have suggested that there is hoarseness, instability and fatigue of voice during menstrual cycle.

Summary and Conclusion

The present study aimed to investigate voice characteristics during the premenstrual stage of the luteal phase (25th day to 28th day of the menstrual cycle) and post menstrual stage of the follicular phase (10th to 13th day of menstrual cycle).

A total of 20 subjects, 10 female Carnatic classical singers who have passed/pursuing senior levels in Carnatic vocal music and 10 females who did not have any vocal training were considered for the study. All the subjects were in the age range of 20 to 27 years.

The sustained phonation samples of the vowels of |a|, |i| and |u| at comfortable pitch and loudness were recorded once in premenstrual stage (phase1) and once in post menstrual stage (Phase2) using Sony digital portable mini-disc tape recorder. Acoustic analysis was done using MDVP software of CSL–4500. The aerodynamic measure that is, vital capacity was measured during these two phases using Vitalograph–2120.

Statistical analysis was conducted using SPSS version 10. In general the results indicated that voice characteristics of both singers and non-singers were not significantly different for majority of acoustic parameters of /a/ and /i/ during phase1 and phase 2. But for the phonation of /u/ in non-singers there was significant increase noticed only for Fatr in phase 2. When comparison was made between singers and non-singers, voice quality was found to be better in singers than non-singers in both the phases.

Vital capacity of both singers and non-singers was better during phase 2 compared to phase 1 though significance was absent. The results also showed that in phase1 the vital capacity of singers was lower than non-singers but this was not significant.

As there is no confirmatory evidence in the literature for voice changes due to hormonal variations during menstrual cycle and owing to the fact that the sample size of the present study was small, the results of the same cannot be generalized across singers and non-singers.

Suggestions for future studies

- The study could be repeated on a larger sample.
- Further studies could measure the hormone levels through blood, saliva or urine samples so that the exact levels of concentration of the ovarian hormones during menstrual cycle can be estimated and correlated with clinical voice measures.
- Studies could include voice samples recorded over a span of few menstrual cycles for each subject to ascertain whether there is variation in voice across menstrual cycles.

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