Acoustic Measure of Hormone Affect on Female Voice During Menstruation

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Abstract

Purpose: *The purpose of this study was to use connected speech patterns in acoustic analysis of voice to determine if variations in vocal patterns can be detected during different phases of the menstrual cycle. It was hypothesized that natural hormonal changes during menstrual cycle would alter the acoustic characteristics of voice.*

Method*: This descriptive research design acoustically analyzed 175 audio recorded female voice samples from 35 subjects. The points of measure included the following phases: menstrual, follicular, ovulatory, luteal and premenstrual. Eight parameters were statistically analyzed for significance: mean fundamental frequency, jitter, relative average perturbation, shimmer, peak-to-peak amplitude variation, noise to harmonic ratio, degree of voice breaks, and number of voice breaks.*

Results: *A statistical analysis of data reliability between the 1st and 2nd menstrual periods showed no statistically significant differences for any of the eight acoustic parameters. No statistically significant differences were found for any of the acoustic parameters between subjects using estrogen/progesterone contraceptives and those that were not using them.*

Conclusion: *None of the eight acoustic parameters examined demonstrated statistically significant differences in the four different hormonal phases of the menstrual cycle. Results suggest hormones are not implicated in voice change parameters measured during menstrual cycle.*

The purpose of this study was to use connected speech patterns in acoustic analysis of vice to determine if variations in vocal patterns can be detected during different phases of the menstrual cycle. Recently, a number of studies have suggested the female voice has an increased perceived attractiveness during specific periods of menstrual cycle. The implication is that during these periods hormones peak causing a change in the female voice. For example, Pipitone and Gallup (Pipitone et al., 2008) rated the perception of 38 female voices across four equally spaced periods during the menstrual cycle. A total of 152 voice samples were evaluated by 30 male and 30 female raters. The results indicated a perceived increase in voice attractiveness as subjects approached a greater probability of conception during the menstrual cycle. The perceived effects of voice change during menstrual cycle are well documented among classically trained singers. Ryan and Kenny (Ryan et al., 2007) identified six female singers who indicated their voices were greatly affected during menstrual cycle. Voice recordings from the six subjects taken at the first and mid cycle periods were randomly presented to both the subjects and their instructors for analysis.

The subjects were able to identify when during their cycle the recordings were taken as well as reported greater effort required during the menstrual cycle to perform vocal tasks. The perceived differences in voice change during menstrual cycles are supported in studies of vocally trained groups as well. Brodnitz (Brodnitz, 1971) documented a case of sudden dysphonia of a professional female singer occurring one day prior to menstruation onset. Gynecological examination revealed abnormally low levels of corpus luteum hormone caused the recurring dysphonia prior to menstruation. Perceptual characteristics of vocal fatigue, loss of intensity, and variances in harmonics are indicative of premenstrual vocal syndrome (Abitbol, Abitbol, & Abitbol, 1999). In such cases hormone replacement therapy typically restores the voice to within normal parameters.

Additional studies implicate the effects of hormones on voice. Baker (Baker, 1999) studied the cases of four women who sought otolarygological examinations following suspected iatrogenic dysphonia. Withdrawal from hormonal medications coupled with voice therapy eventually reduced some of the adverse vocal symptoms. If hormones can have a physiological effect on the female voice then it would stand to reason that oral hormone medication for contraception use would indicate such effects as well. However, research associated with oral contraception effect on voice presents inconclusive. While two studies present with significant changes in vocal perturbation as a result of oral contraception use (Amir, Biron-Shental, Tzenker, & Barer, 2005; Amir, Kishon-Rabin, & Muchnik, 2002) two other studies identify no changes in glottal airflow (Gorham-Rowan & Fowler, 2008) or voice onset timing (Morris, Gorham-Rowan, & Herring, 2009).

The limited variation on vocal performance by the use of oral contraceptives would indicate hormonal impact may be pre-conditioned in some manner. To examine the pre-conditional effects of hormones on voice several researchers have examined impact during various stages of menstrual cycling. One group of researchers analyzed the fundamental frequency changes occurring during menstrual cycle without hormone replacement therapy and during menopause with two different hormone replacement agents. Differences in fundamental frequency for the three subject groups presented with no significance (Mendes-Laureano, Ferriani, Reis, Aguiar-Ricz, Valera, Kupper, et al., 2006). The study was limited however to the measurement of one vocal parameter and one point of measure during targeted periods. No significance was found when assessing across two points within the menstrual cycle among adolescent females (Meurer, Garcez, von Eye Corleta, & Capp, 2009). Acoustic measures of fundamental frequency, rate of speech, and intensity were taken during follicular and luteal phases of the cycle.

These results are in spite of a previous study conducted by Whiteside (Whiteside, 2004) measuring voice onset times during the same phases of cycle examined by the Meurer study (Meurer et al., 2009). Results indicated a significant effect during menstrual cycle phase on the voice onset times of plosive production. However, this study fell short in a low number of subjects (seven) evaluated and in producing significant standard deviation between means. Replicating the Whiteside study by expanding the number of subjects (15 women and 20 men) and contrasting gender groups, Wadnerkar, Cowell, and Whiteside (Wadnerkar et al., 2006) evaluated the means of voice onset times in naturally occurring whole words from gender and low/high estrogen and progesterone samples. Results indicated significant relationship between cycle phase and voice onset timing of plosives. Comparative gender differences within the study implicated hormones as agents. The limited number of subjects continues to call into question the generalization of results.

Using a similar research design, Raj, Gupta, Chowdhury, and Chadha (Raj et al., in press) increased the number of subjects (100), contrasted reproductive and postmenopausal age groups, measured five acoustic parameters (H/N ratio, s/z ratio, perturbation, fundamental frequency, & maximum phonation) and included five points of measure during the cycle (menstrual, follicular, ovulatory, luteal, and premenstrual). While the postmenopausal group presented with significance in relationship between hormonal balance and voice changes, the reproductive group presented with no significance in any of the vocal parameters measured. One potential limitation of the study however, was the limited acoustic input resulting from the stimulus of single phoneme production. Still, the inconsistent findings between studies suggest examination of pre-conditional variables is needed.

If a similar research design were implemented using a connected speech pattern for acoustic analysis would the outcomes show significant differences? Digital recordings of connected speech samples are standard when analyzing voice characteristics. Commercially available acoustical analysis programs generally do not correlate with each other secondary to the various types of acoustic signals presented in the voice sample. For this reason researchers often assess samples limited to phoneme or syllable stimuli and not to connected speech. However, perceptual analysis of speech implies an interpretation of emotional variance (i.e. seduction) that is accounted for in connected speech patterns not in phoneme or syllable stimuli. Researchers have argued that acoustic measures take into account the contextual need for a broader connected speech sample (Alpert, Pouget, & Silva, 2001; Johnstone, van Reekum, Kirsner, & Scherer, 2005). Alpert, Pouget, and Silva (Alpert et al., 2001) recognized the need for acoustic analysis of "free speech" patterns in order to affirm clinical impressions of depression in the voice. They hypothesized that free speech (spontaneous connected speech) required cognitive activity associated with emotion patterns that would not be acoustically detected in non-free speech patterns.

Results indicated acoustic analysis of connected speech patterns were directly correlated to clinical impressions of emotional speech. Johnstone (Johnstone et al., 2005) corroborated this finding with a study to determine the degree in which emotionally charged speech could acoustically reflect factors other than arousal. Acoustic analysis of speech samples from 30 subjects measuring four vocal parameters correlated with the arousal perceptually identified during elicitation from computer game tasks. Speech recognition software uses this same theory to program computer voice differentiation of energetic states within voice. Acoustically analyzing connected speech patterns of 17 subjects, Krajewski, Wieland, Sommer and Golz (Krajewski et al., 2008) validated a software program's ability to recognize psychological changes in cognitive speech planning. Using the same speech sample phrase from all of the subjects, the program was able to analyze as many as 8,500 high level speech features not found in non-connected speech samples. It is hypothesized that inconsistent results in voice analysis during different phases of the menstrual cycle may be the result of limited acoustic stimuli. Broadening the acoustic input from phoneme/syllable to connected speech would provide the computer greater variance from which to measure specific parameters.

Method

Subjects

The institutional review board approved the inclusion of thirty-five female university students as participants in this study. The number of subjects for this study met or exceeded the numbers in all previously stated research with the exception of the Raj, Gupta, Chowdhury, and Chadha study (Raj et al., in press). All subjects reported experiencing regular menstrual cycles. Exclusion criterion from the study included use of antibiotics or medications associated with upper respiratory infection. Additional exclusion criterion included pregnancy, use of fertility drugs, and previous surgery related to pharynx or larynx. Those taking birth control during the study were classified according to type of contraceptive used to later determine if acoustic differences were associated with the birth control. Subjects interacted with a female student research assistant in completion of both the demographic survey and menstruation cycle diaries. The diaries documented a four week period including dates menstrual period began, ended, and next period began. Once the diaries were complete the student research assistant scheduled recording dates. Although subjects were notified that acoustic measures of voice were analyzed for research they were not told of the specific purpose in detecting voice differences during the cycle. This was done to insure the subjects were not motivated to alter voice during recording sessions.

Recording Procedure

Subjects were divided into three groups determined by the number of days in their cycle. For those with a 32 day cycle recordings were acquired on days 2 (menstrual phase), 8 (follicular phase), 16 (ovulatory phase), 24 (luteal phase), and 32 (premenstrual phase) following the start date of menses. For those on a 28 day cycle recordings were acquired on days 2 (menstrual phase), 7 (follicular phase), 14 (ovulatory phase), 21 (luteal phase) and 28 (premenstrual phase). For those with a 26 day cycle recordings were acquired on days 2 (menstrual phase), 6 (follicular phase), 13 (ovulatory phase), 18 (luteal phase), and 26 (premenstrual phase) following the start date of menses. A total of 175 audio recordings were acquired for analysis. The total number of recordings analyzed in this study exceeded those of all previously stated research with the exception of the Raj, Gupta, Chowdhury, and Chadha (Raj et al., in press) research. These five recording sessions, therefore, closely correlated with five hormonal conditions of estrogen and progesterone concentrations in the blood: Condition1(1st menstrual period) – low estrogen and progesterone; Condition 2 – increased (increasing) estrogen and low progesterone; Condition 3 – high estrogen and low progesterone; Condition 4 – high estrogen and progesterone; and Condition 5 (2nd menstrual period) – low estrogen and progesterone. Condition 5 was basically a repeat of the hormonal status of condition 1 for verification of the reliability of condition 1.

Each session was audio recorded in a quiet room using a microphone connected directly to a computer operating voice analysis software to capture the audio signal. Subjects were positioned approximately 8 to 10 inches from the microphone while reading aloud the following stimulus sentence: "Yesterday did the kindergarten children watch television after breakfast?" The stimulus sentence was designed to maximize auditory input for analysis by including multi and mono syllable words, words allowing for voice onsets, words containing a variety of fricatives, plosives and sonorants, and varied intonation contours. The stimulus sentence is a connected speech pattern allowing for optimal change in perturbation, fundamental frequency, voice breaks, amplitude, and harmonic to nose ratio. Requesting the production of a carefully chosen sentence with marked phonetic composition for analysis is in keeping with previous research examining acoustic characteristics of voice patterns (Neel, 2009; Reich & Redenbaugh, 1985).

Analysis of Recordings

Once the audio signal was captured a speech analysis software generated means for 34 voice parameters. Of these, the following eight parameters were statistically analyzed for significance: mean fundamental frequency, jitter, relative average perturbation, shimmer, peak-to-peak amplitude variation, noise to harmonic ratio, degree of voice breaks, and number of voice breaks. The sampling rate for analysis was set at 44.1 kHz.
Results A multiple variable analysis was calculated to summarize the quantitative data of both the cycle length and period length of the subjects. Measures of central tendency, variability, and shape were determined. Significant departures from normality would tend to invalidate many of the statistical procedure normally applied to this data. In this case the data did not show standardized skewness values or standardized kurtosis values outside of the expected range. Multiple sample comparisons were calculated for each of the 8 voice parameters targeted. This procedure compared the data for each of the variables by determining the F-test in the ANOVA. Table 1 notes the eight measured parameters with the specific data results for each of the five menstrual periods. Although variance is noted for each of the parameters from one period to the next, no significant differences between the means of the targeted variables were noted.

As a result, regardless of any paradigms noted in the data, interpretation of such paradigms is invalid secondary to lack of statistical significance.

Table 1 Statistical Analysis of Acoustic Variables During Menstrual Cycle Phases

	Menstrual (+/-S.E.)	Follicular (+/-S.E.)	Ovulatory (+/- S.E.)	Luteal (+/- S.E.)	Premenstrual (+/-S.E.)	Analysis of Variance p value
Mean Fundamental Frequency	215 (4.9)	220 (4.7)	220 (5.3)	222 (5.0)	222 (5.2)	0.86 (n.s.)
Jitter	3.9 (0.19)	3.8 (0.19)	3.9 (0.19)	3.6 (0.13)	3.6 (0.16)	0.66 (n.s.)
Relative Average Perturbation	2.2 (0.11)	2.1 (0.11)	2.2 (0.11)	2.0 (0.08)	2.0 (0.09)	0.54 (n.s.)
Shimmer	10.9 (0.29)	11.0 (0.33)	11.1 (0.31)	10.8 (0.29)	10.8 (0.30)	0.93 (n.s.)
Amplitude Variation	46.5 (1.34)	47.23 (1.38)	47.44 (1.16)	47.63 (1.18)	46.0 (1.05)	0.88 (n.s.)
Noise to Harmonic Ratio	0.29 (0.01)	0.30 (0.01)	0.31 (0.01)	0.29 (0.01)	0.29 (0.01)	0.72 (n.s.)
Degree of Voice Breaks	39.4 (1.73)	37.9 (1.22)	36.66 (1.12)	36.63 (1.13)	36.9 (1.31)	0.53 (n.s.)
Number of Voice Breaks	10.5 (0.39)	10.9 (0.48)	10.5 (0.54)	11.0 (0.48)	10.65 (0.48)	0.93 (n.s.)

n.s. = not statistically significantly different

As a control for data reliability the acoustic parameters taken during menstrual period 1 were compared to those of menstrual period 2 as shown in table 2. Using the Student's t-Test no statistically significant differences were found between the acoustic variables measured during menstrual period 1 compared to menstrual period 2.

Table 2 : Reliability of Measurements of Acoustic Variables

	Menstrual Period 1 Mean (S.E.); Median	Menstrual Period 2 Mean (S.E.); Median	Student's t-Test p-value
Mean Fundamental Frequency	215 (4.9); 214	222 (5.2) 222	0.32 (n.s.)
Jitter	3.9 (0.19); 3.6	3.6 (0.15); 3.7	0.29 (n.s.)
Relative Average Perturbation	2.2 (0.11); 2.1	2.0 (0.09); 2.1	0.21 (n.s.)
Shimmer	10.9 (0.29); 10.5	10.8 (0.30); 10.8	0.83 (n.s.)
Amplitude Variation	46.5 (1.34); 45.9	46.0 (1.05); 46.2	0.79 (n.s.)
Noise to Harmonic Ratio	0.29 (0.01); 0.28	0.29 (0.01); 0.29	0.81 (n.s.)
Degree of Voice Breaks	39.4 (1.73); 38.6	36.9 (1.31); 35.0	0.27 (n.s.)
Number of Voice Breaks	10.5 (0.39); 10.0	10.6 (0.48); 11.0	0.87 (n.s.)

n.s. = not statistically significantly different

In addition, a comparison of medians between variables of contraceptive use and non-contraceptive use was calculated using the Mann-Whitney and the Komogorove-Smirnov tests. As shown in table 3, no statistically significant differences in any of the eight acoustic parameters were noted. This indicated there was no apparent affect of hormonal birth control on vocal acoustics.

Table 3 Statistical Analysis of the Effect of Contraceptives on Acoustic Variables

	No Contraceptive Mean (S.E.); Median	Contraceptive Mean (S.E.); Median	Mann-Whitney Test p-value	Kolmogorov-Smirnov Test p-value
Mean Fundamental Frequency	214.5 (6.6); 215.6	215.7 (7.2); 211.7	0.73 (n.s.)	0.62 (n.s.)
Jitter	3.99 (0.28); 3.83	3.81 (0.25); 3.59	0.58 (n.s.)	0.85 (n.s.)
Relative Average Perturbation	2.28 (0.16); 2.20	2.17 (0.16); 2.01	0.50 (n.s.)	0.73 (n.s.)
Shimmer	11.26 (0.52); 10.46	10.58 (0.30); 10.70	0.48 (n.s.)	0.78 (n.s.)
Amplitude Variation	47.26 (1.52); 46.48	45.85 (2.15); 45.87	0.63 (n.s.)	0.58 (n.s.)
Noise to Harmonic Ratio	0.30 (0.02); 0.29	0.29 (0.01); 0.27	0.62 (n.s.)	0.93 (n.s.)
Degree of Voice Breaks	39.0 (2.56); 38.7	39.7 (2.41); 37.8	0.83 (n.s.)	0.73 (n.s.)
Number of Voice Breaks	10.4 (0.65); 10.0	10.7 (0.49); 11.0	0.51 (n.s.)	0.21 (n.s.)

n.s. = not statistically significantly different

Discussion

The effect of hormone fluctuations during menstrual cycles on the female voice is inconclusive. While the perceptual data suggest changes in voice do occur, acoustic analysis suggests no changes occur in the voice parameters measured. This study successfully addressed the weaknesses noted in previous studies that may call into question the accuracy of patterns noted. Specifically, the number of points within the cycle at which data was collected, the number of voice parameters analyzed, and the type of acoustic signal elicited from the subjects. Although greater variable controls were established with this study the results indicated acoustic patterns measured were not significantly altered during menstrual cycle. This suggests variables other than natural hormonal changes at the points measured within the cycles and within the specific acoustic parameters chosen contribute to the perceptual differences in voice noted by previous studies. The inclusion of “free speech” patterns in this study assist in validating the “no affect” result of natural hormone changes of voice parameters measured during menstrual cycle. Allowing subjects the opportunity to naturally express emotion through a connected speech pattern (i.e. intonation, perturbation, voice onsets, etc.) provided broader data variables for analysis. However, effects on additional acoustic parameters have not been ruled out.

It is possible that hormonal effect significantly altered acoustic signals in a manner not detected by this study. These findings corroborate those of the Raj, Gupta, Chowdhury, and Chadha (Raj et al., in press) regarding the outcomes of the reproductive group where no significant differences in five points of acoustic measures were noted. In addition, the results of this study also corroborate previous data suggesting that hormonal effect on fundamental frequency has no statistically significant measurable difference (Mendes-Laureano, Ferriani, Reis, Aguiar-Ricz, Valera, Kupper, et al., 2006; Meurer, Garcez, von Eye Corleta, & Capp, 2009). As previously noted (Pipitone & Gallup, 2008) perceptual changes in voice may be secondary to non-vocal cues such as facial expression, body language, eye contact, or even the mood of the listener. This study suggests that such variables might be implicated in the perceptual differences of female voice patterns during menstrual cycles. For those perceptual studies that ruled out non-vocal cues as influencing variables, the noted perceptual changes may be the result of acoustic signals such as voice onset time which were not addressed in this study.

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