A Pre-post Comparison of Vocal Loading Using Infrared Thermography in Phono-normals

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Project Report

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ARF Project Title: **A Pre-post Comparison of Vocal Loading Using Infrared Thermography in Phono-normals**

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Abstract

Introduction: The application of Thermal Imaging has been used extensively in medical field like cancer detection, dentistry, dermatology, fever scanning, brain imaging and so on. Owing to the colloidal force between vocal folds in continuous oscillation, there is heat generation and dissipation on the vocal folds. To document the amount of heat on the surface of vocal folds, a novel, non invasive method using thermal imaging technique is used in this study. The present study made an attempt to measure and empirically document the impact of prolonged loud reading (vocal loading) on throat temperature and few acoustic parameters in normo-phonic adult individuals.

Method: Two groups of normo-phonic adult individuals participated in this study. 30 males and 30 females included in group I and II, respectively. Participants were within the age range of 18 to 40 years. In pre-experimental condition (condition I) throat temperature and phonation of vowel /a/ sample were recorded as a baseline measurement. Participants were asked to read a Kannada material for 30 minutes at 70-80 dB SPL in condition II (experimental condition). In post-experimental condition (condition III) similar temperature and phonation of vowel sample were recorded again. Thermal imaging camera along with SmartView software employed to measure the throat temperature. PRAAT software used to analyse F0 and MDVP software of CSL used for jitter and NHR analysis.

Results: Throat temperature increased significantly after loud reading (post vocal loading) by 2.5 ºC in group I (males) and 2.81 ºC in group II (females) when compared to baseline measurement (condition I). No alterations or changes found for jitter and NHR measures after post-experimental condition (condition III). F0 increased significantly by 11 Hz in group I and 10 Hz in group II after loud reading (vocal loading) in condition III. No correlation was found between temperature measure and acoustic measure in this study.

Conclusions: Thermal imaging method is found to be a useful method in documenting certain subtle changes of vocal behaviours following vocal loading. It can be used as a supplement method along with acoustic, aerodynamic, physiologic and subjective (self rating) analyses in vocal loading studies that compare pre-post vocal changes.

Keywords: Vocal load, Thermal Imaging, Acoustic analysis, Prolonged loud reading, Infra-red thermography.

Chapter I

INTRODUCTION

Voice is the laryngeal modulation of the pulmonary air stream, which is then modified by the configuration of the vocal tract (Michel & Wendahl, 1971). Voice is the sound produced by the movement of vocal folds and which is altered by the transfer function of the vocal tract. Voice is the acoustic signal generated by the vocal folds, which are situated in the larynx for talking, reading, singing, laughing, crying, screaming, etc. Voice communication begins at birth, and it influences nearly every part of human interaction and culture. As an auditory perceptual term, voice can be divided into different parameters such as pitch, loudness, quality, and variability.

Voice production involves a complex and precise control by the central nervous system into a series of events in the peripheral phonatory organs. The vocal fold serves as an energy transducer that is responsible for converting aerodynamic power into acoustic power. Voice is produced by modifying the steady stream of air from the lungs by the vocal folds. The air comes from the lungs, and the force pushing the air out of the lungs occurs from the contraction of the abdominal and chest muscles; and the relaxation and recoil of the diaphragm. Thus, anything that hampers the normal action of the diaphragm, chest, or abdominal muscles may have a significant impact on the voice.

A normal healthy person can use voice for 3-5 hours in a day without having any vocal load issues. Any voice problem at this time indicates that there is a possibility of real voice difficulty. The patient's voice cannot be evaluated over several hours in a clinical setup, and to overcome this, vocal loading tests are performed by simulating a vocal load situation for a shorter period. (https:// wevosys.com/ products/ lingwaves/ lingwaves_vocal_loading_test.html).

Many researchers have developed gadgets for calculating vocal loading, and some of which were speech time/intensity accumulator (Masuda, Ikeda, Manako, Koniyama, 1993); voice accumulator (Buekers, Bierens, Kingma, & Marres, 1995); noise exposure analyzers (Airo, Olkinuara, & Sala, 2000); and voice dosimeter (Popolo, Svec, & Titze, 2005). For measuring the exposure to self-induced tissue vibration in speech, three vocal doses, namely distance dose, time dose, and cycle dose were calculated by Titze and Popolo (2003). Svec, Titze and Popolo (2005) quantified three important vocal doses, namely, (a) time dose, (b) distance dose, and (c) cycle dose. Time dose is the total duration the vocal folds are vibrating. Distance dose is defined as the total distance traveled by the vocal folds. Cycle dose is defined as the total number of cycles accomplished by the vocal folds on its oscillatory trajectory.

Morrow and Connor (2011) measured the voice use profile using ambulatory phonation monitor (APM), which included F0, dB SPL, time dose, cycle dose, and distance dose. Also, the same was measured between the elementary classroom and music teachers using an ambulatory phonation monitor. The authors reported that music teachers had higher vocal loading parameters than elementary classroom teachers.

The gadgets reported previously used automatic methods to measure and announce the vocal dose results. Some of these gadgets are not commercially available as they are still in experimental modification. Also, the available devices are expensive and cannot be afforded by every clinician in their voice clinics. Furthermore, expertise training and knowledge are required to operate and interpret the data in such expensive devices.

Infrared thermography (IRT) is a non-invasive technique that allows one to measure and visualize infrared radiation. Thermal imaging is a technique that is capable of mapping the temperature distribution on the human skin. The spectrum of the visible light has a limited range of wavelengths between 390 nm to 700 nm, whereas electromagnetic radiation has a wide range starting from 700 nm up to 1mm wavelength. Out of which, wavelengths between 8 μm to 15 μm is referred to as the thermal infrared range, which is used for thermal imaging (Tattersall, 2016) procedure.

IRT is used to detect on the surface and sub-surface and on-line monitoring of process (Maldague, 2001). The average human body core temperature is approximately 37 ±0.5°C, with surface temperature slightly lower and more variable, depending on ambient conditions (Kelly, 2006).

Numerous pathological conditions can make either complete or local thermal anomalies, e.g. rise in temperature due to inflammation, infection, trauma and malignancy or fall in temperature due to ischemia. Since, anatomical abnormalities leads to physiological alterations, such as temperature change as observed in other classical medical imaging, IRT would serve as a potential tool for very early detection of these conditions (Chojnowski, 2017). There are multiple factors influencing the human body temperature such as age, recording time, activity level, weather, emotions, state of consciousness, hormonal imbalance and medications (Kelly, 2007).

There are many factors which influence measurement of temperature such as emissivity, background temperature, medium, camera sensor followed by images processing (figure 1). Emissivity is described as how the objects interact and emit radiation. Ideally a black body has the highest emissivity of 1 and the values keep decreasing for different objects. For a human skin, emissivity ranged between 0.97 and 0.99 having a standard deviation of 0.01 (Steketee, 1973; Togawa, 1989; Villaseñor-Mora, Sanchez-Marin & Calixto-Carrera, 2009). A constant background temperature helps in better analysis of the human skin.

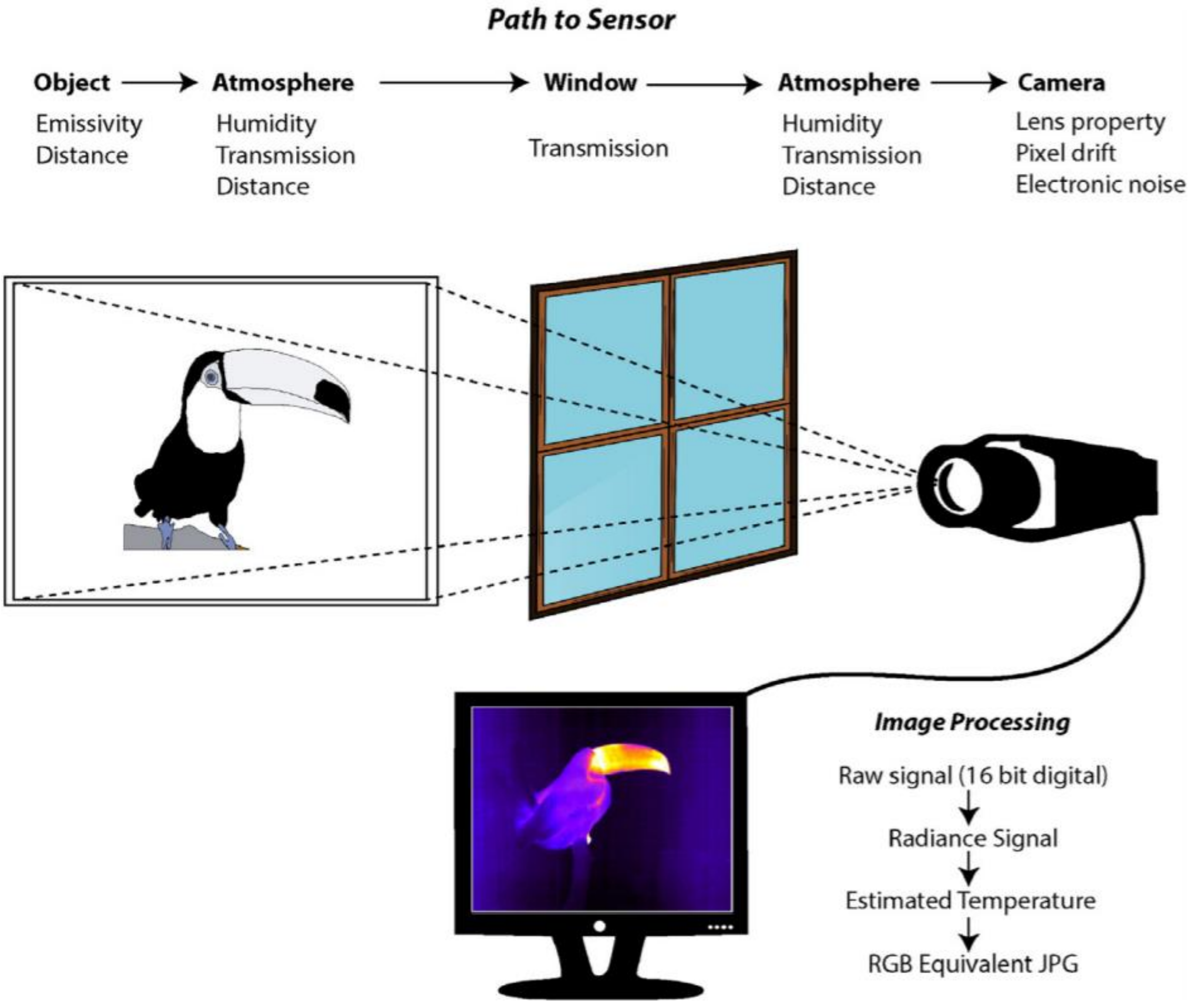

Figure 1: Typical path-flow information from object to the sensor and the image processing. (Adapted from "Infrared thermography: A non-invasive window into thermal physiology" by G. J. Tatersall (2016), *Comparative Biochemistry and Physiology Part A, 202,* p.84.)

Humidity has a major role to play when the room / environment is filled with 100% relative humidity, the human body could get condensed resulting in heat gain, wherein, heat can also be lost by evaporation (Vardasca & Simões, 2013). Although, the resolution of the camera has little role to play (Ammer, 2005), camera with best resolution is always preferred for calculation of temperature (Fernández-Cuevas et al., 2015).

Owing to the continuous repeated vibration of vocal folds during prolonged speaking task, there is heat generation on the surface of the vocal folds. This would be because of colloidal forces happened between the vocal folds. Cooper and Titze (1985) indicated that there was presence of heat generation and dissipation in the vocal fold following vocal loading tasks. Literature on the effect of prolonged loud reading (vocal loading) on voice quality was published in normo-phonic individuals by employing acoustic, aerodynamic and perceptual/self rating scales. Thermal imaging usage in capturing the heat that is generated on vocal folds (at surface level) following prolonged loud speaking/reading (induced vocal loading) is not been explored. Hence, the present study made an attempt to empirically document the temperature near throat region prior to and post loud reading in normo-phonic adult individuals.

Chapter II

REVIEW OF LITERATURE

The literature review was done under the following headings:

1) Vocal loading
2) Methods of measuring vocal loading
3) Use of thermal imaging in medical diagnostics

1) Vocal loading

Vocal load has been measured, in the past, using prolonged voice use (Hill, Oates, Healey, & Russell, 1988; Gelfer, Andrews, & Schmidt, 1991; Stemple, Stanley, & Lee, 1995; Vilkman, Lauri, Alku, Sala, & Shivo, 1999). Individuals who use their voices excessively on a daily basis or with some type of voice disorders have a common complaint i.e. vocal fatigue (Colton & Casper, 1996). It has been used extensively in the literature as a method to understand how vocal fatigue leads to laryngeal adjustments and the negative consequences (Welham & Maclagan, 2003).

2) Methods/variations in measuring vocal loading

2.1 Duration

In the previous studies, inducing vocal fatigue ranged from 15 minutes (Linville, 1995) to 2 hours (Stemple, Stanley, & Lee, 1995; Solomon & DiMattia, 2000; Remacle, Finck, Roche & Morsomme, 2012) in the regular or predetermined intensity, with or without vocal training, and on normal or symptomatic individuals. Vilkman et al. (1999) studied the effects of vocal loading on 80 normal adults (40 males and 40 females) who involved in a vocal loading task for 45 minutes of 3 times in one day. Fujiki, Chapleau, Sundarrajan, McKenna and Sivasankar, (2017) induced

30 minutes of vocal loading on 16 vocally healthy adults (8 males and 8 females). Bhoominathan, Anitha, Shenbagavalli and Dinesh (2010) and Xue, Kang, Hedberg, Zhang and Jiang (*in press*) instructed participants to read a book for an hour or until they reported of as themselves fatigued.

2.2 Intensity

The longer and louder a person uses his or her voice, the greater the strain on the voice mechanism (Buekers, 1998). Remacle et al. (2012) incorporated in their study as 60-65 dB and 70-75 dB on 50 females. Laukkanen et al. (2004) employed 70 dB intensity level on 24 females. Whitling, Rydell and Ahlander (2015) used 6 females and 5 males in the presence of loud speech babble. Boominathan et al. (2010) employed vocal loading task in their study at 75-80 dB SPL.

2.3 Acoustic measures

Usage of voice over a prolonged period can lead to rise in fundamental frequency (F0) which can potentially serve as an index for typical voice use (Ben-David, & Icht, 2016). Kelchner, Toner and Lee (2006) investigated the effects of vocal loading in normal adolescent males and reported elevated F0. Laukkannen, Ilomaki, Leppanen and Vilkman (2008) examined F0, sound pressure level (SPL), and perturbation measures for both phonation as well as reading tasks at two levels; one at habitual conversation loudness and another at very loud level in female primary school teachers. The study reported increase in F0, SPL, and alpha ratio and decrease in values of perturbation measures which reflected increased activity of voice production muscles and swelling of the vocal fold tissues and as a result of adaptation to loading. Vilkman, Lauri, Alku, Sala and Sihvo (1999) studied the effect of vocal loading from morning to afternoon and reported increase in F0, SPL and decrease in jitter (%) and shimmer (dB) in the afternoon. Pellicani, Ricz and Ricz (2015) studied on 20 Brazilian young women, before and after vocal loading by measuring different acoustic parameters like fundamental frequency, low frequency which was increased after vocal loading and other parameters such as amplitude tremor intensity index (Atri), amplitude variation (vAm), noise-to-harmonic ratio (NHR), and soft phonation index (SPI) was decreased after 1 hour of vocal loading task. Xue et al (*in press*) measured F0, jitter, shimmer and noise-to-harmonic ratio in 10 participants after vocal loading and reported a significant difference in F0 and no significant difference for jitter, shimmer and noise-to-harmonic ratio. Frequency related measures like phonation fundamental frequency (pF0), standard deviation of phonation fundamental frequency (SD pF0), and speaking (SF0) were reported to be significantly increased after vocal loading compared to baseline (prior to teaching) as reported by Rajasudhakar and Savithri (2009); Rajasudhakar and Savithri (2010).

2.4 Aerodynamic measures

Whitling, Rydell and Ahlander (2015) attempted to study phonation threshold pressure (PTP) after vocal loading task. Since PTP was unstable, it was not considered for analysis and was not used. Vilkman et al (1999) found rise in PTP after vocal loading. Solomon and Di Mattia (2000) reported increase in PTP after 2 hours of vocal loading at conversational pitch and 10%, 50% and especially at 80% of the pitch range. Xue et al (*in press*) reported significant rise in PTP after 15 minutes of vocal loading task and gradual increase in the subsequent 45 minutes. Boominathan et al. (2010) reported decrease in maximum phonation time (MPT) and increased s/z ratio after 60 minutes of vocal loading. Kelchner, Lee and Stemple (2003) found significant increase in mean air flow and significant decrease in MPT in adults with unilateral vocal fold paralysis after reading task. However, Remacle et al. (2012) reported increase in MPT after 2 hours of vocal loading.

3) Use of thermal imaging in medical diagnostics

Thermal imaging is a technique which is capable of mapping the temperature distribution on the human skin. Infra-red thermography (IRT) has many applications in the medical field and has been extensively used for breast cancer detection (Kosus, Kosus, Duran, Simavli, & Turhan, 2010), diabetic neuropathy (Ring, 2010), fever scanning (Bitar, Goubar, & Desenclos, 2007), brain imaging (thermoencephaloscopy) (Shevelev, 1998), dentistry and dermatology (Fikackova & Ekberg, 2004), muscular pain and shoulder impingement syndrome study (Park, Hyun, & Seo, 2007) and others. IRT has also been used in acupuncture treatment (Lo, 2002), and forensic medicine (Cattaneo, Giancamillo, Campari, Martrille, & Jouineau, 2009). Thermometers were used to measure diurnal changes of temperature in normal subjects by Martine in 1740. Any change in the temperature of the body was an indicator of illness and in 1871, Wunderlich and Woodmanm (1871) proved it by systematically studying the temperature of subjects suffering from fever and compared with that of normal subjects. They also established a normal range for temperature between 36.3 °C and 37.5 °C beyond which should be considered as an indicator of illness.

The use of infrared thermography to measure the vocal loading has not been systematically documented in phono-normal individuals. Lokheshwar (2017) examined the changes in temperature using infrared thermography in 10 males at pre, during and post loud reading task and found increase in temperature in the vocal region from 37.07 °C to 38.12 °C for 7 out of 10 participants. The author did not consider female participants and participants were varying in degree of body mass index (BMI). Also, few subjects read Kannada reading material and other read

English reading materials. The findings of the above study cannot be generalized as the participants considered was less and temperature measurements in the neck region depends on muscle mass that vary in different individuals of varying BMI and also the frequency of distribution of voiced and voiceless consonants might not be similar in Kannada and English languages. Cooper and Titze (1985) have stated that there is generation and heat dissipated in the vocal fold tissues during mechanical vibration and it was found to rise from 0.1°C to 0.8 °C in an excised bovine larynx using fine-wire thermocouples.

Need for the study

Effects of vocal load have been documented using acoustic and aerodynamic measurements in the past. One of the aerodynamic measure, maximum phonation time (MPT) reported to increase (Remacle et al., 2012) and decrease (Boominathan et al., 2010) after vocal loading tasks. Similarly, the acoustic studies have shown increase in fundamental frequency (F0) (Rantala et al., 2002) and no change in F0 (Stemple et al., 1995) after vocal loading tasks. Similarly, studies have shown that short-term frequency perturbation measure (jitter) has increased (Gelfer et al., 1991), decreased (Stemple et al., 1995) and no significant change (Verstrate et al., 1993) after vocal loading tasks. The results of the acoustic studies did not unravel the vocal loading effect and they are far from conclusive.

Also, gadgets like speech time/intensity accumulator (Masuda et al., 1993); voice accumulator (Buekers et al., 1995); noise exposure analyzers (Airo et al., 2000) and voice dosimeter (Popolo et al., 2005) were not commercially available to measure vocal loading. Way back in 1985, Cooper and Titze (1985) reported that there was heat generation and dissipation in vocal fold after inducing vocal load. Thermal imaging technique is a proven method to document the temperature distribution on the human skin (Freitas, 1999).

However, no comprehensive knowledge exists on changes in temperature dynamics on the throat/larynx which could be recorded by thermal camera when subjected to vocal loading tasks in phono-normal individuals. There are no published studies on using IRT as a measure to infer the change in temperature before/after vocal loading. Therefore, the present study investigates the effects of controlled prolonged loud reading on changes in temperature in the throat (vocal) region using IRT in healthy individuals (phono-normals).

Objectives of the study

1. To examine the changes in temperature at throat (vocal) region, if any, before and after vocal loading task.
2. To compare the changes in temperature between males and females, if any (gender difference).
3. To document the changes in acoustic parameter (F0, jitter and NHR) through PRAAT and MDVP using phonation task before and after vocal loading.
4. To correlate between thermal and acoustic measures.

Chapter III

METHOD

Participants: Sixty healthy (phono-normal) adults in the age range of 18-40 years participated in the study and were divided into two groups where, Group I consisted of 30 males and Group II included 30 females. Only those participants who had perceptually normal voice in terms of pitch, loudness, and quality, and native speakers of Kannada were selected. Further, participants who had history of smoking, alcohol, laryngeal pathology, intubation, neurological disorders, and surgery/accidents/trauma to laryngeal system, history of sustained or prolonged use of medication for any medical conditions, and Body Mass Index (BMI) above or below average were excluded from the study; average BMI is (18.5 to 22.9). Further, participants were included in the study whose voice was normal based on the results from Multidimensional Voice Profile (MDVP) and Dr. Speech voice assessment tools.

Procedure: Informed consent was taken from the participants for the study and was initially briefed about the objectives of the study.

The study was carried out in three conditions;

Condition I: Pre-experimental

Condition II: Experimental

Condition III: Post-experimental

Condition I: Pre-experimental phase involved baseline voice assessment of participants. The participants were made to sit in an air-conditioned room of 25 ºC and multiple baseline temperature at the neck/throat (vocal) region (between chin and collarbone) was taken using thermal image camera at the intervals of 5 minutes till the temperature got stabilized with the distance of 60 cms. Once stabilized, the temperature was measured and then participants were asked to phonate vowel /a/ for about 4 to 5 seconds which was recorded in a sound recorder held by the examiner at a distance of 10 cm from the participant's mouth.

Condition II: Experimental phase included prolonged loud reading task. Participants were asked to read a book or a reading material of their interest in Kannada for 30 minutes at 70-80 dB SPL in sitting posture. While reading aloud, intensity level was monitored by using sound level meter by the examiner. Participants were reminded gesturally to increase the loudness when there was drop in intensity. Participants were instructed to indicate when they are no longer able to continue the task or till they exhibit signs of vocal fatigue to stop the experiment and the duration will be noted down.

Condition III: Post-experimental phase, immediately after the experiment, measurement of throat temperature and phonation sample of vowel /a/ was recorded.

Instrumentation: Temperature was measured using a thermal imager camera Fluke (Ti32, Fluke, Everett, and Washington, USA) and sound recorder Olympus (LS-100, Japan) for recording phonation of vowel /a/ sample. Intensity of reading was monitored using Sound Level Meter (TECPEL DSL-331, Taiwan). Models of the instruments are represented in figure 2, figure 3 and figure 4, respectively.

Figure 2: Thermal imaging camera (Fluke Ti32).

Figure 3: Sound recorder (Olympus LS-100).

Figure 4: Sound Level Meter (TECPEL DSL-331).

Analyses: The audio samples were saved in .wav format and were analyzed using Multi-Dimensional Voice Program (MDVP) and PRAAT software for acoustic measurements. The images captured using thermal camera was saved in .IS2 format and were edited using the SmartView (version 4.0) software. The palette was set to Rainbow for better representations of range of temperatures. Emissivity was set to 0.98 and background temperature to 25 ºC. The average temperature of the vocal region (between chin and color bone) are represented in figures 5 and figure 6.

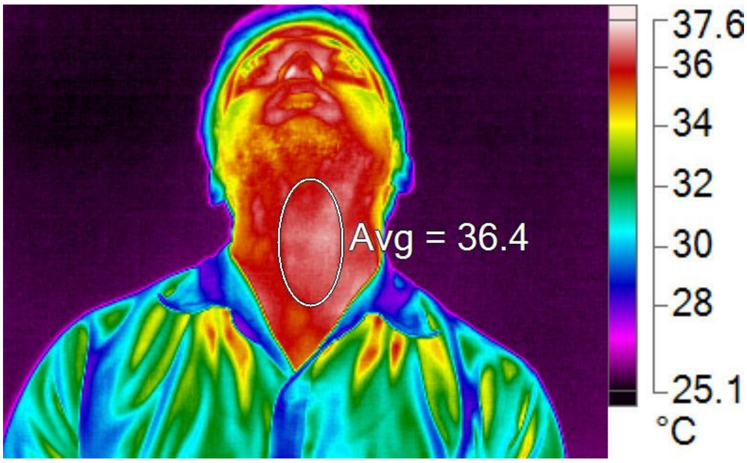

Figure 5: Temperature distribution at vocal region during pre-reading condition.

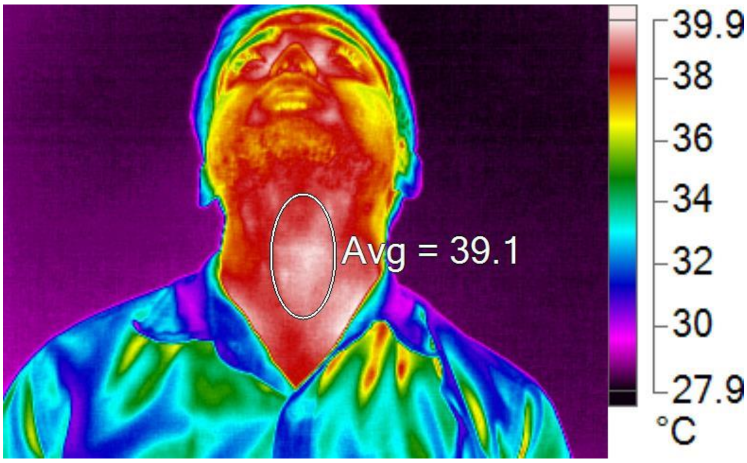

Figure 6: Temperature distribution at vocal region during post-reading condition.

Statistical analyses: Statistical analyses were carried out using a standard statistical package, SPSS software (Statistical Package for Social Sciences, version 21). The raw data (thermal measures and acoustic measures such as fundamental frequency, jitter and noise-harmonic ratio) obtained from 60 participants were subjected to Shapiro-Wilk test of normality. On the first trial, a total of 8 outliers were removed to attain normal distribution of the data. On the second trial, data pertaining to jitter was not normalized despite removal of extra 5 outliers. Hence, the data was retained with a total of 52 participants. Descriptive statistics such as Mean and Standard deviation on fundamental frequency, jitter, noise-harmonic ratio and temperature were computed in both the groups. Non-parametric tests were administered only for jitter. Mann-Whitney U test was performed to find the mean difference between the groups (males and females) and Wilcoxon signed rank test was performed to compare the within-group means. However, parametric test such as repeated measures of ANOVA was computed for fundamental frequency, noise-harmonic ratio and temperature for between-group and within-group comparison. Thermal and acoustic measures were correlated using Pearson correlation test between fundamental frequency, noise-harmonic ratio and temperature, and Spearman's correlation between jitter and temperature.

Chapter IV

RESULTS

The independent measures were duration of prolonged loud reading, intensity level of reading which was fixed for 30 minutes and at the level of 70 to 80 dB SPL, respectively. Gender was an attribute variable in the study. The dependent variables were temperature and the acoustic parameters such as average fundamental frequency (F0), jitter, and noise to harmonic ratio (NHR).

In the following section, the results are described under five sub headings;

1. Thermal measure
2. Fundamental frequency (F0)
3. Jitter
4. Noise to harmonic ratio (NHR)
5. Correlation between thermal and acoustic measures

1. Thermal measure

Mean values of the temperature increased from condition I to condition III in both males and females. Mean temperature increased by 2.5 Celsius and 2.81 Celsius in males and females, respectively. Repeated measures of ANOVA results revealed significant main effect on temperature difference [F (1, 50) = 899.01, $p<0.05$] between condition I and condition III with an effect size of 0.947 was noticed. However, no significant interaction effect was observed. Figure 7 represents the mean throat temperature before and after vocal loading. There is no statistical significant difference [F (1, 50) = 3.66, $p>0.05$] found between group I (males) and group II (females). Results of mixed ANOVA were tabulated in table 1.

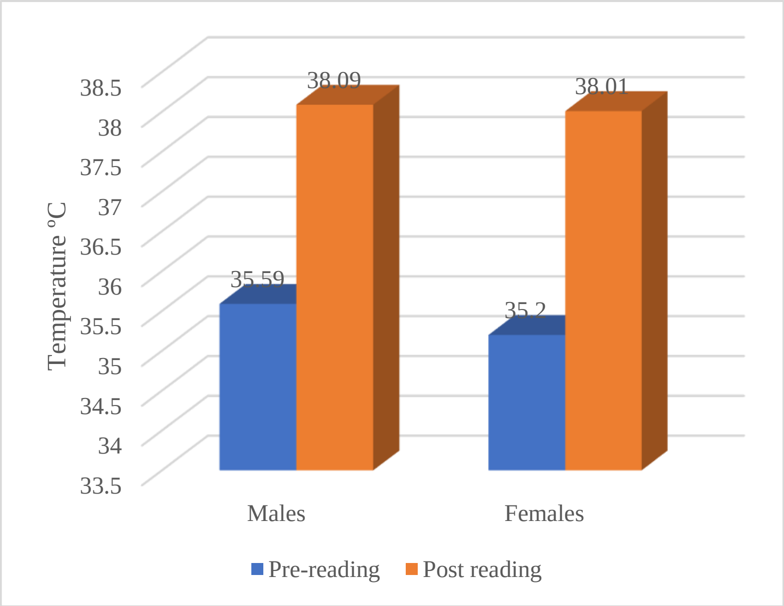

Figure 7: Mean throat temperature for males and females at pre-reading and post reading conditions

Table 1: *Results of mixed ANOVA*

Parameters	**F (1, 50)**	***p* value**
Temperature		
Temperature	899.01	0.000*
Group	3.66	0.061
Temperature*Group	3.06	0.086
Fundamental frequency		
F0	62.87	0.000*
Group	252.11	0.000*
F0*Group	0.12	0.722
Noise to harmonic ratio		
NHR	0.55	0.461
Group	2.11	0.041
NHR*Group	0.78	0.380

*indicates significant at 0.05 level

2. Fundamental frequency

The mean F0 values were found to be increased from condition I to condition II in both the groups. It was increased from 120.77 Hz to 131.95 Hz in group I and 204.52 Hz to 214.73 Hz in group II. Results of repeated measures of ANOVA revealed statistical significant main effect [F (1, 50) = 62.87; $p<0.005$] of fundamental frequency and no significant interaction effect [F (1, 50) = 0.12; $p>0.05$] was observed. Figure 8 represents the mean fundamental frequency before and after vocal loading in group I (males) and group (females).

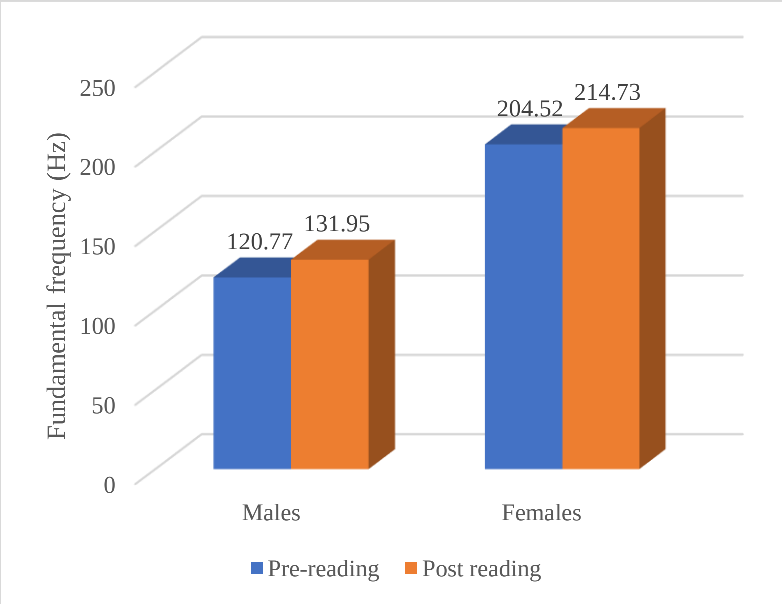

Figure 8: Mean fundamental frequency in males and females at pre-reading and post reading conditions

3. Jitter

Mean jitter value for group I in condition I and condition III are 0.58 and 0.66, respectively. Whereas for group II, the mean jitter value in condition I and condition III are 0.77 and 0.5, respectively. Results of Wilcoxon Signed Rank test revealed no statistical significant difference within-groups (/z/ = 0.579; $p>0.05$). That is, jitter increased in the post vocal loading task (condition III) in group I and jitter decreased after vocal reading task (condition III) in group II from condition I. This increase or decrease in the jitter value is found to be not statistically significant in both the groups. Similarly, Mann-Whitney U test revealed no significant difference between groups (/z/ = 0.018; *p*>0.05) for condition I and for condition III (/z/ = 1.803; *p*>0.05). Figure 9 represents the mean jitter value for both the groups before and after vocal loading.

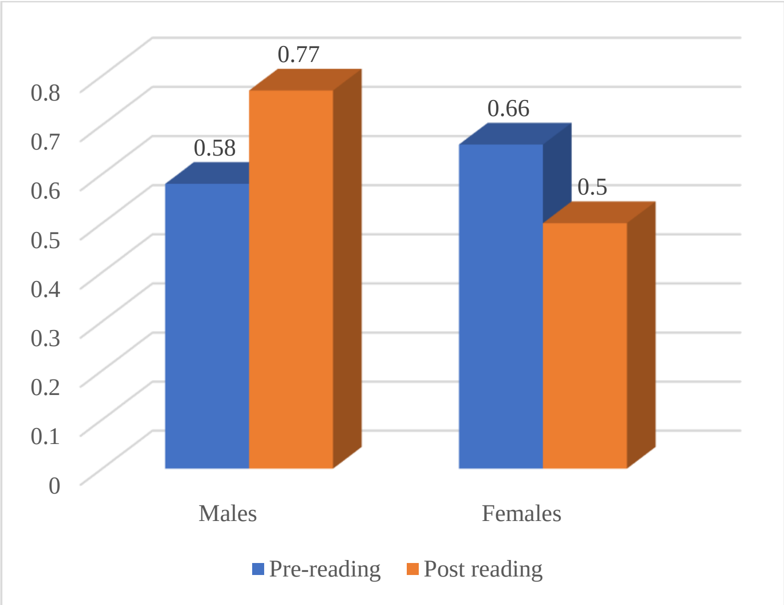

Figure 9: Mean jitter value for males and females at pre-reading and post reading conditions

4. Noise to harmonic ratio (NHR)

Mean NHR for condition I in group I and group II are 0.133 and 0.13, respectively and for condition III in group I and group II are 0.136 and 0.12, respectively. Results of repeated measures of ANOVA revealed no statistical significant difference between-groups [F (1, 25) = 2.11, *p*>0.05] as well as within-group [F (1, 25), *p*>0.05] was found. The NHR values were similar to baseline values even after 30 minutes of vocal loading task in both males (group I) and females (group II). Figure 10 shows the mean NHR value in both the groups before and after vocal loading.

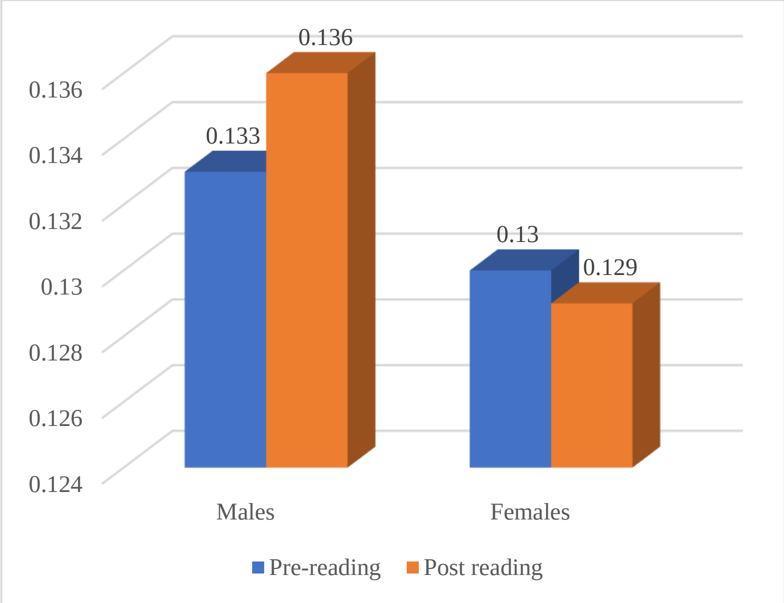

Figure 10: Mean NHR value for males and females at pre-reading and post reading conditions

5. Correlation

Results of Pearson's correlation test revealed no correlation observed for males (group I) and females (group II) between throat temperature and F0 and between throat temperature and NHR during condition I and condition III. Table 2 shows the results of Pearson's correlation between throat temperature and acoustic parameters (F0 and NHR) and results of Spearman's correlation between throat temperature and jitter. Also, results of Spearman's correlation revealed moderate correlation observed between throat temperature and jitter for males (group I) in condition I. The obtained correlation was also statistical significant. Whereas, there is no correlation noticed between throat temperature and jitter parameter for females in both condition I and III and for males in condition III.

Table 2: *Results of Pearson's and Spearman's correlation test*

Tests	**Correlation**	**Conditions**	**Group I (Males)**		**Group II (Females)**	
			r	***p***	**r**	***p***
Pearson's	T versus F0	Condition I	0.34	p>0.05	0.30	p>0.05
		Condition III	-0.08	p>0.05	0.105	p>0.05
	T versus NHR	Condition I	-0.05	p>0.05	-0.08	p>0.05
		Condition III	0.06	p>0.05	-0.32	p>0.05
Spearman's	T versus jitter	Condition I	-0.53	P<0.05*	-0.006	p>0.05
		Condition III	0.28	p>0.05	0.067	p>0.05

(T: Throat temperature; * indicates significance at 0.05 level)

Chapter IV

DISCUSSION

The aim of the present study was to investigate the changes in thermal and acoustic parameters of voice before and after induced vocal loading in males and females. The other purpose of this investigation was to examine gender difference across thermal and acoustic parameters. The study also aimed to correlate between thermal and acoustic measures.

The results of the study are discussed under the following sections:

i) Thermal measures

ii) Acoustic measure (F0, Jitter and Noise to harmonic ratio)

iii) Correlation between thermal and acoustic measures

(i) Thermal measures

Statistical significant increment in throat temperature is observed from condition I to condition III in both the groups. However, no statistical difference was observed between groups. Internal energy and temperature of a body is determined by the amount of vibration of particles which is expressed in the form of heat known as infrared radiation (Akintola, 2010). Metabolic substrates break down during physical activity providing energy for cellular metabolism. Circulation transfers heat produced at core to the skin to prevent dangerous elevation in the core temperature (Magee, Zachazewski, Quillen & Manske, 2010). In physics, the *second law of thermodynamics* states that heat flows from an object at a higher temperature to an object at a lower temperature (Holzner, 2016) which explains transfer of heat from core to skin. Increased continuous oscillation of vocal cords results in higher frequency resulting in rise of temperature (Shanmugasundaram & Rajasudhakar, 2018a). The results of the present study are in consonance with the findings of Shanmugasundaram et al., 2018).

(ii) Acoustic measures

1) Fundamental frequency (F0)

Average F0 is the steady vibration of the vocal folds for a stipulated time. A statistical significant difference is observed from condition I to condition III in both the groups. As observed from figure 8, there is an increase of F0 in both the groups following prolonged loud reading. Increased F0 could possibly be due to increased strain on intrinsic muscle of larynx such as thyroaryteniod (TA) muscle. When the cover and transition layers of vocal folds stiffens, the TA muscle slackens subsequently resulting in increased rate of vibration leading to higher F0 (Stemple et al., 1995). Results of the present study supports the increment in F0 post vocal loading task as reported by Vilkman et al. (1999); Remacle et al. (2012), Hemaraja (2012); Stemple et al. (1995); Shanmugasundaram and Rajasudhakar (2018 a, 2018 b). Further, the increase in fundamental frequency is not only limited to vocal fold's vibratory characteristics but also because of shape and configuration of the vocal tract (Jayakumar & Savithri, 2012).

2) Jitter

As mentioned in the results, the findings were in line with the earlier findings of Burzynski and Titze (1986); Scherer, Titze, Raphael, Wood, Ramig and Blager (1991); Verstraete, Forrez, Mertens and Debruyne, (1993); Remacle et al. (2012); Xue et al. (*in press*) who did not establish any significant changes on jitter percent after prolonged loud reading. According to Xue et al. (*in press*) there are two possible reasons for fluctuation in the jitter. First, F0 rise is observed due to increase in laryngeal tension. Jitter is known to fall and F0 rises (Orlikoff & Kahane, 1991). Second, vocal fatigue may lead to difficulty in sustaining voice stability after loud reading tasks. However, the present study did not find any significant increase or decrease in jitter value after prolonged loud reading/vocal loading task in both the groups.

3) Noise to harmonic ratio (NHR)

The study found no increase or decrease in NHR value after prolonged loud reading (vocal loading) in both the groups. The findings of the present study are in line with the results of Krishna and Nataraj (1995); Hemaraja (2012); Xue et al. (*in press*) who found no significant difference in noise related measures after vocal loading. However, it was in contrast with the findings of Boominathan et al. (2010) who reported higher NHR values after vocal loading. The difference in the findings obtained in the present study and study by Boominathan et al. (2010) could be because of differences in the methodology.

(iii) Correlation between thermal and acoustic measures

It is found that there is not much of a correlation between thermal and acoustic measures (F0, NHR and jitter). However, moderate correlation is seen between acoustic parameter (only jitter) and throat temperature in condition I (pre-reading) in group I (males). The same was not seen in condition III (post-reading) in group I. The reason behind the moderate correlation between temperature and jitter in males (group I) is not known which need to be studied with more number of participants. Method of measurement could be one of reason for no correlation between temperature and acoustic measures. For example, the acoustic results are directly depended on the vocal folds vibrations and it is an offline measurement recorded through the microphone. Whereas, measurement of temperature is at the surface level and it is an online evaluation of heat emitted on the external skin that is influenced by emissivity distance, humidity distance and so on. Apart from the parameters such as F0, jitter and NHR few other acoustic parameters can be considered in the further studies for correlation with thermal measure in vocal loading studies.

Chapter V

SUMMARY AND CONCLUSIONS

The present study was aimed to investigate the changes in the thermal measures and selected acoustic parameters of voice at two conditions; prior to and following an induced vocal loading task in normo-phonic adult individuals. The study also aimed to investigate the gender effect i.e. between groups (males and females) and to correlate between thermal and acoustic measures. A total of 60 participants (30 males and 30 females) within the age range of 18 to 40 years participated in the study. An induced vocal loading task of prolonged loud reading for a duration of thirty minutes was used in the study, at a reference intensity of 70 to 80 dB SPL.

The study was conducted in three conditions: (i) Pre-experimental condition (condition I) involved baseline measurements of throat temperature (after throat temperature stabilising in an air-conditioned room at 25 ºC) and acoustic parameters such as average fundamental frequency, jitter, and noise to harmonic ratio using a sustained phonation of vowel /a/; (ii) Experimental condition (condition II) included prolonged loud reading task in Kannada for 30 minutes at 70 to 80 dB SPL; and (iii) In post-experimental condition (condition III), measurements of thermal and acoustic parameters were measured again using a sustained phonation of vowel /a/.

The results of the present study revealed several points of interest;

First, there is an increase in throat temperature after prolonged loud reading in both the groups. The average increase in throat temperature in males was 2.5 ºC and 2.81 ºC in females. The present study found that the average throat temperature increased by 2.65 ºC in normo-phonic adult individuals following vocal loading task. Increased oscillation of vocal folds generate heat that dissipated across different layers of the vocal folds and exceeding certain limit may result in development of organic lesion on the vocal folds.

Second, among acoustic parameters, average fundamental frequency (F0) proved to be successful in documenting the subtle changes of voice due to vocal loading task of prolonged loud reading. The values of F0 increased after vocal loading task in both males and females by 11.18 Hz and 10.21 Hz, respectively. Literature hinted that the thyro-arytenoid muscle, one of the intrinsic muscles of larynx undergo weakness after prolonged loud reading. Both cover and transition layer of vocal folds contribute for F0 rise.

Third, jitter and noise to harmonic ratio (NHR) failed to show any alterations or variations after vocal loading in both the group of participants.

Fourth, the present study did not find any correlation between thermal and acoustic measures such as F0, jitter and NHR. Acoustic parameters like jitter and NHR are not that sensitive measure to document the subtle changes in the vocal behaviour after prolonged loud reading in normo-phonic adult individuals. Correlation can be established in further studies between throat temperature and visual inspection of vocal fold changes in videostroboscopy before and after vocal loading.

Future directions

The application of thermal imaging in voice science field is a novel and budding step in conducting research particularly in vocal loading and its effect on voice quality. The results of the present study warrants further research in the following directions,

i. Studies on various clinical populations of voice disorders with a complaint of vocal fatigue can be considered.

ii. Studies can employ using different vocal loading tasks such as singing or teaching or narration.

iii. Studies incorporating correlation between throat surface temperature and visual examination of the vocal folds for documenting voice changes before and after loud reading can be done.

iv. Other acoustic parameters including multi-parametric approaches, Ceptral parameters [Cepstral Peak prominence (CPP) and Smoothened Cepstral Peak Prominence (CPPs)] and self rating scales on vocal effort/difficulty like Vocal Handicap Index (VHI) can be used to document the subtle voice changes after vocal loading.

v. Similar type of studies can be done in paediatric population (before pubertal period) to understand the vocal changes and compensation reactions after vocal loading.

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List of papers presented

International

1. *Shanmugasundaram, L., & Rajasudhakar, R., & Ravindran, K.* **"Infrared Thermography as a Tool to Infer Vocal Load: A Preliminary Observation".** Presented at 47th Annual Symposium: Care of the Professional Voice, 30th May to 3rd June 2018, Philadelphia, Pennsylvania, USA.

2. *Shanmugasundaram, L., & Rajasudhakar, R.* **"Changes in Throat Temperature and Acoustic Voice Measures in Vocally Healthy Adults after Vocal Loading".** Presented at 5th Hong Kong Speech and Hearing Symposium, 1-4th November 2018, Shatin, Hong Kong.

National

1. *Rajasudhakar, R., & Shanmugasundaram, L.* **"Effect of Vocal Loading on Throat Temperature in Young Phono-normal Adults".** Presented at 2nd Nitte Voice Assessment and Therapeutics (Ni-VAT) Conference, 22-25th February 2018, Mangalore, India.

List of papers published

International

1. Shanmugasundaram, L., & Rajasudhakar, R. (2018 *a*). Effect of Vocal Loading on Throat Temperature in Young Phono-normal Adults. *Journal of Laryngology and Voice, Vol. 8 (1),* 14-18.

2. Shanmugasundaram, L., & Rajasudhakar, R. (*2018 b*). A Preliminary Study Using Thermal Imaging on Voice and Throat Temperature under Induced Vocal Loading. *International Journal of Health Sciences and Research, Vol. 8; Issue: 11,* 8-14.