Immediate Effects of the Straw Phonation Exercise and Systemic Hydration on Vocal Loading in Carnatic Classical Singers

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1. **Introduction**

The term occupational voice is getting popular with more people depending on their voice for work (Williams, 2003). Professional voice users (PVU) are those for whom voice is crucial to their profession and is essential for their livelihood (Gunasekaran, Boominathan, & Seethapathy, 2016; Lerner, Paskhover, Acton, & Young, 2013). Due to higher vocal demands, PVU experience higher incidence and prevalence rates of voice problems compared to the general population (Roy et al., 2004; Titze, Lemke, & Montequin, 1997).

1.1 Voice problems in singers

Among PVU, singers are pointed out as the most demanding vocal group (Petty, 2012). Singing is a vocal art performed with modulations and accurate breath control. The singing voice is the product of a delicate balance of physiologic control, artistry, and techniques (Teachey & Kahane, 1991). Similar to speech, singing also demands well-coordinated respiratory, phonatory, articulatory, and resonatory systems under the prime control of the nervous system. However, unlike speech, singing involves a much more prolonged and sophisticated voice production with precise adjustment in the larynx, adding greater demands on the vocal mechanism. To assure success in their profession and to meet their performance demands, singers are thus required to have an expanded vocal ability when compared to non-singers.

Literature suggests that because singers expend a great deal of energy in their performance and undergo enormous stress while singing, they are more prone to develop voice problems (Phyland, Oates, Greenwood, 1999; Sapir, 1993). In the Indian context, few studies have documented the voice problems in Carnatic classical singers. A self-reported voice survey on Carnatic classical singers reported a high career (35.5%) and point prevalence (22.6%) of voice problems (Devadas, Kumar, & Maruthy, 2018). Also, around 22% of the Carnatic singers missed out on 2-5 singing performances due to voice problems. Profiling of vocal and non-vocal habits of Carnatic singers pointed to several poor vocal hygiene habits such as throat clearing and loud speaking/singing for extended durations (Boominathan, Nagarajan & Krishnan, 2004). Further, in another study, clinical voice analysis of 45 Carnatic singers with a voice problem indicated 42.2% and 35.5% complained of change in voice and difficulty in singing higher pitches, respectively (Arunachalam, Boominathan & Mahalingam, 2014). Around 31.1% of singers reported difficulty in reaching lower pitches, dryness of throat, and vocal fatigue. Furthermore, 26.7% of singers reported discomfort and pain while singing, and 22.2% of singers reported difficulty in sustaining voice for an extended duration, throat tightness, and strain while singing. Several studies have investigated the phonotraumatic behaviors exhibited by singers such as loud singing, speaking fast, dominating conversations, frequent throat clearing, non vocal habits such as clenching teeth, tensing jaw and tongue, tightening neck muscles, less or no vocal warm-up and cool-down exercises (Broaddus-Lawrence, Treole, Mccabe, Alen, &Toppin, 2000; Erickson, 2012; Garcia & Lopez, 2017; Kitch & Oates, 1994; Miller &Verdolini, 1995; Neto & Meyer, 2017; Sapir et al., 1996).

1.2 Vocal loading tasks

Several attempts have been made to understand the anatomical and physiological changes that happen in the larynx after prolonged and consistent usage of voice. One of the approaches used in these studies is challenging the optimal functioning of the larynx called vocal loading. Studies have found that optimal, vocally demanding tasks are used to understand the function of the laryngeal system and identify those who are vulnerable to develop vocal pathology (Fujiki & Sivasankar, 2017). Vocal loading tasks in these studies refer to the voice task rather than a compromised state of the larynx. In other words, vocal loading tasks provide insight regarding the mechanisms underlying healthy laryngeal function (Fujiki, Chapleau, Sundarrajan, McKenna, & Sivasankar, 2017). Based on a review study, the most commonly used vocal loading task is loud reading with various intrinsic factors, such as reading at different intensity levels, using forced mouth-breathing while reading, loud reading using pressed voice quality at high and low range level, and reading aloud for 40 minutes in a multi-talker-babble noise (Fujiki & Sivasankar, 2017). Other tasks used in the literature were the repetition of sustained vowels, 45 minutes of child-directed speech in the presence of 65 dB multi-talkers babble background noise, phonating vowels, and singing. Various studies have reported adverse changes in aerodynamic measures (Solomon, Glaze, Arnold R, et al., 2003; Chang & Karnell, 2004), acoustic measures (Gelfer, Andrews, & Schmidt, 1991; Guzmán, Malebrán, Zavala P, et al, 2013) , and self-perceptual measures (Boominathan, Anitha, Shenbagavalli et al, 2010; Whitling, Rydell, & Ahlander, 2015) produced as a resultant of vocally loading tasks.

1.3 Vocal warm-up exercises

Voice therapy typically follows several management philosophies, which include hygienic voice therapy, symptomatic voice therapy, psychogenic voice therapy, physiologic voice therapy, eclectic voice therapy. Hygienic voice therapy is one of the most commonly included approaches, which emphasizes on eliminating and modifying phonotrauma. Vocal rest, in combination with hydration, is one of the commonly suggested intervention strategies to restore vocal function or improve voice quality (Yiu & Chan, 2003; Van der Merwe, 2004; Prater, Deem, & Miller, 2000). Increasing hydration level is the most suggested method (Erickson-Levendoski & Sivasankar, 2011), which is regulated through systemic and surface mechanisms (Sivasankar & Leydon, 2010). Systemic hydration refers to oral water intake and absorption at the cellular level (Sivasankar & Leydon, 2010), while superficial hydration refers to the fluid composition at the surface lumen of the vocal folds (Sivasankar & Leydon, 2010). Recent studies have highlighted the positive effects of systemic hydration on vocal loading (Solomon & DiMattia, 2000; Solomon, Glaze, Arnold R, et al., 2003). For professional singers, prolonged vocal use leads to a lot of heat dissipation and an increase in vocal fold friction, which might bring alterations in the fluid composition of the vocal mechanism. Increased vocal use also leads to an increase in stiffness and a decrease in viscosity of the vocal folds, resulting in fatigue and effortful movement (Judelson, Maresh, Anderson, et al., 2007; Leydon, Sivasankar, Falciglia, et al., 2009). Water also serves as a lubricant and shock absorber in the vocal folds to overcome the adverse effects of vocal misuse or abuse (Jéquier & Constant, 2010). With studies highlighting how systemic dehydration is detrimental to voice production, exacerbating the negative phonatory effects of vocal loading (Solomon & DiMattia, 2000; Fisher, Ligon, Sobecks, et al., 2001; Verdolini, Min, Titze et al., 2002), it is essential to understand the immediate effects of systemic hydration on vocally loaded singers.

There is a wide range of vocal warm-up exercises practiced throughout the world by the singers as a part of physiologic voice therapy (Titze, 1996; Titze, 2002; Nix & Simpson, 2008). Such physiologic voice therapy approaches include voice therapy programs that have been devised to alter or modify the physiology of the vocal mechanism directly. Studies have shown, regular and consistent practice of vocal warm-up exercises before a performance/concert having positive effects in singers with normal vocal functioning (Mendes, Rothman, Sapienza & Brown, 2003; Amir, Amir& Michaeli, 2005). Some of the recent studies have shown that straw phonation may improve the functioning of the vocal mechanism (Titze, 2002; Laukkanen, Titze, Hoffman & Finnegan, 2008; Laukkanen, Horacek & Havlik, 2012). Straw phonation exercises are one of the most frequently used methods to create semi-occlusion in the vocal tract (Titze, 2006). With straw phonation, there is an increase in air pressure above the vocal folds, keeping them separated during phonation and reducing the impact collision force due to the narrowing of the vocal tract (Meerschman et al., 2017). To accomplish this, the individual semi-occludes the vocal tract by phonating through a straw or tube. The biofeedback produced as a result of blowing air bubbles to the water surface increases the individual's awareness of his or her healthy voice production.

Need for the study

Since singers are elite vocal performers and singing demands healthy vocal mechanisms, it is necessary to study the effect of vocal loading in singers. Vocally loaded voice with a prolonged use might hamper the overall voice quality of the individual. Because singers place a high demand on the voice, it is necessary to prioritize effective measures to preserve their voice and identify those individuals who are susceptible to develop VP. In doing so, we can identify those singers who are susceptible to develop voice problems. As their vocal folds have to regularly traverse up-down the scale, and sing in high intensities, we hypothesize that singers, in our case Carnatic classical singers, may have different vocal loading effects when compared to other professional voice users and non-singers.

Several studies in the literature have reported semi-occluded vocal tract exercises (SOVTEs) such as straw phonation and humming yield optimal vocal fold adduction and improve singing voice. SOVTEs are characterized by reduction of the cross-sectional area at the distal part of the vocal tract during phonation. The main purpose of the SOVTEs is to improve the vocal fold adduction by increasing the supraglottal pressure which in turn reduces the transglottal pressure. Further, increase in back pressure keeps the vocal folds optimally separated and expected to cause decreased glottal resistance, increased glottal flow, and efficient vocal fold vibration and prevents mechanical trauma to the vocal fold mucosa (Titze, 2006). Since, Carnatic singing style is one of the important singing types of India, it is important to explore the amount of vocal loading experienced by these singers and investigate the effect of straw phonation in water exercises on vocal loading in this group of professional voice users.

Similarly, the importance of systemic hydration in the maintenance of vocal hygiene is well known. However, the immediate effects of SOVTEs such as straw phonation and vocal hygiene measure such as systemic hydration on vocal loading in singers are not well understood.

Aim and objectives

a) To investigate the immediate effects of straw phonation on vocal loading in Carnatic classical singers.
b) To investigate the immediate effects of systemic hydration on vocal loading in Carnatic classical singers.

2. Review of Literature

The purpose the current project was to investigate the impact of straw phonation and systemic hydration on the negative effects of vocal loading. For the same the review of literature is summarized under the following headings:

2.1 The effect of vocal loading on voice measures

It is well known that vocal loading alone adversely affects the voice (Sodersten, Ternstrom & Bohman, 2005). Various studies have made investigations concerning different vocal loading tasks to assess the vulnerability of the laryngeal mechanism. Buekers (1998) carried out a study comparing 20 patients with a history of vocal fatigue with 12 healthy subjects to investigate if voice endurance test could be used to evaluate vocal fatigue. The study concluded no change in electroglottographic values and NHR after a vocal loading task.

Kelchner, Lee, and Stemple (2003) examined the effect of vocal fatigue induced due to prolonged loud reading in 20 adults with unilateral vocal fold paralysis (UVFP). Subjective ratings were significant following loud and prolonged reading even though expert raters did not detect any significant difference. The reading fundamental frequency and mean airflow rates were significantly increased following the task. Maximum phonation times for low pitches significantly reduced post-VLT. The authors concluded that prolonged and loud reading task was successful in generating vocal fatigue in most of the UVFP subjects.

Chang and Karnell (2004) studied the relationship among perceived phonatory effort (PPE), a subjective index of vocal fatigue, and Phonation threshold pressure (PTP). The measures were recorded for five males and females before and after a VLT of prolonged oral reading. The results revealed a strong correlation was found between PTP and PPE scores, supporting PTP to be sensitive to vocal fatigue. No specific trend was seen concerning gender. Also, post vocal fatiguing, PTP recovered within one hour while PPE recovered within one day.

Yiu et al. (2013) carried a vocal loading task of karaoke singing above 80dB in the presence of ambient music in ten males and ten female singers. The results revealed that there was an increase in self-rated effort of voicing while objective measures like fundamental frequency, intensity, speed quotient, and open quotient remained the same before and after singing. However, the mean values of self- rated effort in voicing increased from 0.55 (pre-singing) to 6.95 (post-singing).

Enflo, Sundberg, and McAllister (2013) measured the collision and phonation threshold pressure before and after a VLT of loud and prolonged vocalization (80dB at 0.3m for 20 minutes) in singers and non-singers. Both CTP and PTP increased significantly in the non-singers, while singers reported no substantial effect after the VLT. The authors concluded that the vocalization exercise considered in the study to be insufficient to produce vocal fatigue in trained voices.

Whitling, Rydell, and Ahlander (2015) designed a clinical vocal loading task to track vocal loading and recovery in vocally healthy subjects. Six females and five males were considered for the study. As a part of VLT, the subjects were made to read aloud while making them heard in the presence of background speech babble played at 85 dB SPL. Reading was terminated ones when the participants reported vocal discomfort. Further, the vocal quality and laryngeal physiology were assessed by experts. Participants endured VLT for 3- 30 minutes and reported vocal loading following the VLT. During the VLT, there was an increase in the fundamental frequency and SPL for all the participants. The findings of the present study concluded the VLT to be able to induce self- perceived vocal loading and objective changes to vocal function, without causing damage to vocal function. After 24hours, the self-perceived vocal loading was reported to recede.

Fujiki and Sivasankar (2017) carried a review study of vocal loading tasks in the voice literature. The review study suggested that any vocally loading task designed to compromise the larynx, considering intensity alone as a variable, should likely be over 1 hour in duration. Task shorter than this duration is known for not bringing a significant difference in objective voice measures. While considering a short duration VLT, care should be taken that at least one additional variable (vocal quality, environmental perturbations, non-habitual speech) should be altered. Although the best VLT is unknown, the authors suggest an optimal VLT be one that must include various intrinsic and extrinsic factors to assess the vulnerability of the laryngeal mechanisms. Even though the laryngeal changes are subtle and thus difficult to quantify, the study also summarized the effects of VLT on different voice measures: Participant reported phonatory effort (PPE), Auditory- perceptual, Phonation threshold pressure and acoustic measures. PPE was reported to be the most common measure used in studies related to VLT and was reported to increase in almost all the studies examined in the review. The self-perceptual measure of PPE was more sensitive to subtle laryngeal changes induced by VLTs in comparison to the auditory- perceptual measures. Examination of the literature as a whole concluded that acoustic measures showed varying sensitivity to laryngeal changes induced by VLTs, especially for the fundamental frequency. Jitter, shimmer, and noise-to-harmonic ratio demonstrated limited sensitivity to VLTs. There is a dearth of evidence for the effect of VLTs on cepstral and spectral measures. The authors relate the differences in task type to be probable reason responsible for variation in result pattern across studies.

In the Indian context, an unpublished study carried out by Amrutha (2019) investigated the effects of vocal loading on the acoustical and self-perceptual measurements in ten Carnatic classical singers. The study was conducted across two conditions. During the experimental condition, singers were engaged in a VLT of singing for 95 minutes in the presence of multi-talker babble background noise was considered. For the control condition, participants were engaged in a non-vocal task for 95 minutes. The results revealed that there is no significant difference between the pre and post scores across both the conditions for all the acoustic parameters. The author associated this with the singer's ability to control their breath while singing, as Carnatic Classical singers are known for their open-throated voice. However, perceived phonatory effort and perceived vocal tiredness showed a significant increase in pre and post scores after the vocal loading task for the experimental condition. This effect was not reported for the control condition. However, no definite conclusions can be drawn from the study considering the small sample size.

2.2 The effect of Straw Phonation on voice measures

There is a wide range of vocal warm-up exercises practiced throughout the world by the singers (Titze, 1996; Titze, 2002; Nix & Simpson, 2008). Some warm-up exercises are traditional (taught by singing teachers) where more emphasis is given to whole body warm-up exercises, improving breath support, voice range and voice quality and some are provided by professionals (Speech-Language Pathologists) working with singers emphasizing more on physiological conditions of the vocal fold to avoid vocal fatigue during and after performance. Collectively they are known as semi-occluded vocal tract exercises (SOVTEs). Several studies demonstrated the positive effects of SOVTEs on acoustic, aerodynamic, and perceptual parameters in singers (Guzman, Laukkanen, Krupa, et al., 2013; Dargin, DeLaunay & Searl, 2016; Simberg & Lain, 2007). Humming nasal consonants (m, n) are common traditional warm-up exercises practiced by singers. There are several physiologic warm-up exercises such as the anterior constriction of the vocal tract (lip buzz, lip trills, tongue trills) and artificially lengthening the vocal tract by introducing straw or tube phonation (Portillo, Rojas, Guzman, Quezada, 2018).

Sampaio, Oliveria, and Behlau (2008) studied the immediate effects of two semi-occluded vocal tract exercises: Finger Kazoo and phonation with straw exercise on 23 vocally healthy women. Finger kazoo and phonation with straw exercise revealed positive and similar results for vocal self-assessment. With both the exercises, F0 was found to decrease. However, the auditory perceptual assessment indicated noticeable improvement only after phonation with straw exercise.

Sampaio et al. (2008) studied the immediate effects of straw phonation practiced for one minute for two times in 23 singers with no laryngeal pathology. Participants reported a clearer and stronger voice with straw phonation.

Immediate effects on the long-term average spectrum (LTAS) in speaking voice were assessed after straw phonation exercises in 41 primary school teachers with dysphonic voice were studied (Guzman et al., 2013). Speaking fundamental frequency was extracted from phonetically balanced reading samples collected from the participants. The results revealed significant changes in alpha ratio, LI-L0 ratio, and also the ratio between 1-5 kHz and 5-8 kHz, with straw phonation exercise. However, the authors concluded that exercise could only have a short-term effect on slightly dysphonic voices.

Guzman et al. (2013) conducted a study to analyze the effect of straw/tube phonation in a classically trained singer. The results indicated stronger spectral prominence in the singer's formant and improvement in perceptual voice quality after performing the exercise.

Dargin and Searl (2015) carried a study to investigate the immediate effects of practicing three SOVT exercises on aerodynamic and electroglottographic measures in four singers. The SOVT exercises considered were; Straw phonation, lip trill, and tongue trill. The results revealed an increase in mean airflow, sound pressure level, and EGG closed quotient after the completion of SOVT exercises, though there was marked variability across the singers.

Wistbacka, Sundberg, and Simberg (2016), through a pilot study, attempted to measure the vertical laryngeal position and oral pressure in two subjects during resonance tube phonation in water (RTPW) and phonation with the free tube end in the air. RTPW was found to lower VLP while it increased during phonation with tube end in the air. Also, RTPW generated oral pressure modulation with a bubble frequency of 14-22Hz underwater surface. Thus the study concluded that RTPW lowers the vertical laryngeal position in phonation and creates oral pressure, which induces a massage-like effect.

Andrade, Wistbacka, Larson, Sodernsten, Hammarberg, Simberg, et al. (2016) assessed the effect of SOVTEs (straw phonation, humming, lip trills, and tongue trills) on contact quotient range (CQr) and the difference between F1-F0. Results indicated that all the exercises have a positive effect on the larynx; however, straw phonation and humming were associated with lower CQr values (i.e., steady closed quotient values) and lower F1-F0 values, suggestive of more relaxed phonation compared to lip trills and tongue trills.

Guzman et al. (2017) carried out a study to determine the efficacy of water resistance therapy (WRT) in a long-term period of voice treatment in dysphonic. Twenty participants were randomly distributed to either of the two treatment groups: voice treatment with WRT and phonation with the distal end in the air (TPA). Results showed significant improvements for both groups, that is, a decrease in Voice Handicap Index, subglottic pressure, and phonation threshold pressure. Auditory- perceptual assessment improved only for the TPA group. No significant differences were noted for acoustic and electroglottographic variables. The authors also concluded no significant difference in both the treatment exercises.

Different reasons are quoted for better results obtained with straw phonation and humming compared to lip and tongue trills. Straw phonation and humming builds greater back pressure and leads greater sensation of vibration in facial tissue (Verdolini, Druker, Palmer, Samawi, 1998); straw phonation increases length and inertive reactance of the vocal tract due to lowering of the first formant which reduces average airflow through the glottis and decreases phonation effort (Story, Laukkanen, Titze, 2000); straw phonation and humming is easy to practice as there is only one source of vibration unlike two sources of vibration in tongue and lip trills (Vampola, Laukkanen, Horacek&Svec, 2011).

2.3 The effect of systemic hydration on vocal loading

Chan & Tayma (2002) studied the biochemical importance of hydration and concluded that the visco-elastic properties of the vocal folds are greatly influenced by the hydration content of the tissue. Hydration occurs at different levels in the body. Systemic hydration happens by the ingestion of liquids, which typically involves an intake of 8-10 glasses of water per day (Hartley & Thibeault, 2014). The need for systemic hydration is to keep mucosal tissue healthy. Surface hydration, on the other hand, aims to keep the epithelial surface of the vocal fold healthy (Franca, 2006). It is accomplished by inhalation of humidified air, avoiding drying environment, and nebulization. Multiple studies have investigated the interaction between systemic hydration/ liquid ingestion and vocal loading.

Solomon and DiMattia (2000) studied the effects of vocally fatiguing task and systemic hydration on phonation threshold pressure (PTP), the effort for speaking and vibratory closure pattern, for the same four untrained female voices were considered. All the participants were assessed after 2 hours of loud reading task. The results revealed an increase in PTP after the vocally fatiguing task. The loud reading task also increased the effort of speaking consistently, which decreased after 15 minutes of vocal silence. A spindle-shaped vibratory closure pattern was seen after the loud reading task based on video stroboscopic examination. With systemic hydration, the elevation in PTP was attenuated for three out of four participants, majorly at the highest pitch tested. The authors thus concluded the presence of an interaction between systemic hydration and prolonged loud phonation. However, the authors also highlight the need to replicate similar studies to strengthen current evidence.

A similar study in four vocally healthy men was carried out by Solomon, Glaze, Arnold, and Mersbergen (2003). Participants were assessed before and after the vocally fatiguing task of prolonged-loud reading. All the participants demonstrated detrimental vocal effects with prolonged loud reading. PTP values increased more in under the hydrated condition when compared to the systemic hydrated condition. Based on the laryngeal endoscopy findings, two out of the four participants demonstrated an anterior glottal gap after the loud reading task. However, no definite conclusions were made due to the high between-subject variability.

Franca and Simpson (2012) studied the effects of systemic hydration on vocal acoustics of 38, 18-35year old females. All the participants refrained from the intake of food and liquids 12hours before the testing. Soon after, the pre-test participants were given 1L of water to be ingested in 20 min, after which again acoustic measures were recorded. The results revealed systemic hydration to have a positive impact on shimmer vocal acoustics.

The effect of hydration and vocal rest on the vocal fatigue in 20 young amateur singers (10 males and ten females between 20-25 years)was studied by Yiu and Chan (2003). The goal of such a study was to develop useful educational information for karaoke singers. Half of the singers were given water to drink and short duration of vocal rest during singing, while the other half had to sing continuously without any hydration and vocal rest. Participants who were given water and vocal rest sang for a longer duration when compared to others. Though the participants who were given water and vocal rest did not show significant changes for perceptual, acoustic measures and vocal function, significant changes in jitter and the highest pitch was seen in participants who sang continuously. The authors further concluded, stating the importance of hydration and vocal rest in preserving voice function and quality during karaoke singing.

The effect of vocal loading tasks on vocal function before and after 24 hours of thickened liquid used was carried out by Gorham-Rowan, Berndt, Carter, and Morris (2016). Seven healthy adults were considered for a VLT, which consisted of 3* 10 repetitions of sustained vowel task at 65 to 75 dB SPL. Vocal loudness, subjective ratings, and muscle soreness were higher post-vocal loading. However, measures like NHR, CPP, and F0 did not show a significant effect with vocal loading. Jitter levels substantially reduced post thickened liquid use. However, the authors also concluded that a brief period of thickened liquid intake does not bring a significant effect on vocal function.

A systematic review of the effect of hydration on voice quality in adults was carried out by Alves, Kruger, Pillay, Lierde, and Linde (2017). A significant negative effect was observed due to systemic dehydration (as a result of fasting and not ingesting liquids) on measures like NHR, jitter, shimmer, frequency, and the s/z ratio. Water ingestion significantly improved voice measures like jitter, shimmer, frequency, and maximum phonation time. Steam inhalation also showed significant improvement in NHR, shimmer, and jitter. The authors conclude, emphasizing the importance of incorporating systemic hydration and water intake in vocal hygiene programs.

A study done by Van Wyk and colleagues (2017) studied the effect of hydration on the voice quality of future professional vocal performers. A within-subject study was carried out on 12 females between 18-32 years. The authors found that intake of water had a significant positive effect on the highest frequency singers could produce. The authors related hydrated vocal folds to be more pliable, thus enabling singers to reach higher notes.

To summarize, objective measurement of vocal loading and the immediate effect of straw phonation and systemic hydration are not reported concerning Carnatic classical singers. Since the Carnatic singing style is one of the important singing types of south Karnataka, it is essential to explore the amount of vocal loading experienced by these singers and investigate the immediate effect of straw phonation exercises and systemic hydration on vocal loading in this group of professional voice users. Such studies are essential for the development of evidence-based recommendations for professional voice users.

3. Method

Experiment I- Immediate effect of Straw Phonation on vocal loading in Carnatic classical Singers

A quasi-experimental, within-subject design was used. Each singer participated for two sessions, scheduled on two different days, which included a vocal loading task. The sessions represented treatment (Day 1) and no treatment (Day 2) conditions, respectively.

3.1.1 Participants

A total of twelve participants, two males, and ten females participated in two sessions for this experiment (Table 1). The singers who were more than 15 years of age, who are actively involved in singing during the time of data collection, and were rated as having normal voice on GRBAS (Hirano,1980) scale by a speech-language pathologist were included for this experiment. Singers who had upper respiratory tract infection, hoarse voice, endometriosis, early menopause, and history of hyperthyroidism during the time of data collection were excluded from the study. The participants were between the age range of 17-45 years with mean age of was 28.25 (SD= 8.45). Five participants had a singing experience of greater than15 years, four participants had singing experience of 11-15 years, two participants had singing experience of 5-10 years and remaining one participant had less than five years of experience. Majority of the singers had a habit of singing for 1-3 hours per day (n =9). The participants were either performing artists (n= 6) or music teachers (n= 6). Prior, written consent was taken from all the participants before they participated in the study.

TABLE1. Individual Participant Characteristics for Experiment 1

SL. No	Gender	Age (Years)	Music Training (Years)	Hours of singing/day (hours)	Number of Performances/ year
1	Female	17	<5	1-3	<10
2	Female	23	11-15	1-3	<10
3	Male	39	>15	3-6	>30
4	Female	33	11-15	3-6	<10
5	Female	37	11-15	1-3	<10
6	Female	33	>15	1-3	<10
7	Female	43	>15	3-6	<10
8	Male	29	>15	1-3	10-20
9	Female	20	>15	1-3	<10
10	Female	21	5-10	1-3	10-20
11	Female	22	11-15	1-3	21-30
12	Female	22	5-10	1-3	10-20

3.1.2 Data collection and Procedure

Initially, the Carnatic Classical singers were asked to fill a demographic questionnaire for identification of age, gender, singing experience, time of singing practice, number of hours singing/week. The questionnaire was developed by taking the inputs from previously published study (Devadas, Kumar, and Maruthy, 2018). In the present study, vocal loading task of singing for an hour in a sound-treated room in the presence of background noise (multi-talker babble at 65- 70 dB sound pressure level near the singer's ear) was considered. Each subject completed the experiment by participating for two days. On day 1 (treatment condition), participants completed an eight-minute straw phonation exercise followed by the vocal loading task. The straw phonation exercise is summarized in Table 2. The straw phonation in water exercises are as per the Meerschman et al. (2019) protocol. On day 2 (no treatment condition), participants completed the vocal loading task, without straw phonation exercise. Between day-1 and day-2, a minimum of 2-3 days gap was given. The sessions were counterbalanced across participants. During the gap, the participants only involved themselves in regular singing practice at home and did not involve in giving musical concerts. All the participants were evaluated before and after the vocal loading challenge for acoustic, aerodynamic, and self-rated voice measures, and identical data collection procedures were carried out for both sessions.

TABLE2. Content of Therapy Programme-Straw Phonation Exercise

Step Number	Description	Number of Trials
	Introduction to the materials used • A paper cup filled with water to about 1 inch from the rim • Commercial drinking plastic straw; length 21.5cm, Diameter 0.6cm Correct posture and appropriate breathing	-
1	Gently blow through the straw into the water without any voicing, generating smooth water bubbles at the surface.	10
2	Gently blow through the straw into the water, phonating /u/ (rounded and narrow) through the straw at habitual loudness and pitch (motorboat like sound). Success means generating mild and constant water bubbling with a steady voicing.	10
3	Gently blow through the straw into the water, phonating /u/ (rounded and narrow) through the straw: low- high and high – low pitch maintenance.	Five each
4	Gently blow through the straw into the water, phonating /u/ (rounded and narrow) through the straw with pitch glides: ascending and descending (low-high-low)	5
5	Withdrawal • Phonation of /u/ through the straw, at comfortable loudness, and pitch into the water. • It is followed by slow withdrawal of straw from water medium to air. • Finally, withdrawal of straw from the mouth, while maintaining an easy phonation of /u/.	Each task 5 times

3.1.3 Recording of phonation samples

All the tasks were recorded individually in a quiet room using a digital recorder (Olympus Digital Voice Recorder LS-100). The samples were recorded directly on to the digital voice recorder. The microphone was positioned at the distance of 10cms from the participant's mouth during the recording in a comfortable seated position. Phonation of /a/, /i/, /u/, /s/, /z/ following a deep inhalation (the task was first demonstrated by the experimenter). All the participants were instructed to sit comfortably, take a deep breath, and then sustain the vowels as long as possible while exhaling the air. The participants are expected to phonate continuously at their comfortable loudness and pitch, without any perceived voice breaks, in one single deep breath.

3.1.4 Outcome measurements

a. Acoustic Analysis

Multi-Dimensional Voice Program: The Multi-Dimensional Voice Program (MDVP) software of the Computerized Speech Lab (CSL) 4500 model (KAY PENTAX, New Jersey, USA) was used for the analyses of phonation samples. From each participant out of three trials best /a/ phonation was selected further acoustic and cepstral analysis. The following acoustic measures (Fundamental Frequency and Intensity Measures) were extracted from phonation after MDVP analysis:

a. Mean Fundamental Frequency (MF0): Average value of all extracted period to period fundamental frequency values

b. Highest Fundamental Frequency (FHi): It is the highest of all extracted period- to-period fundamental frequency value in phonation.

c. Lowest Fundamental Frequency (FLo): It is the lowest of all extracted period to period fundamental frequency value in phonation.

d. Jitter Percent: Defined by variation in frequency number of cycles per unit of successive cycles

e. Absolute Jitter: It is the evaluation of the period- to- period variability of the pitch period within the analyzed voice sample, with the voice, breaks excluded.

f. Shimmer Percent: Defined as short-term, cycle-to-cycle variability in vocal fold vibration amplitude

g. The shimmer in dB: It is the dB of the period- to- period variability of the peak- to-peak amplitude within the analyzed voice sample, with voice break areas excluded.

h. Noise to Harmonic Ratio (NHR): It is the average ratio of the inharmonic spectral energy (1500- 4500 Hz) in the frequency range to the harmonic spectral energy in the frequency range (70- 4500Hz).

b. Electroglottographic analysis

Other than these, an Electrographic (EGG) signal was recorded for vowel /a/ using the Real-Time EGG module given by CSL-4500. Recordings were obtained by placing high-frequency, low voltage current passing electrodes externally on either side of the thyroid alae. The electrodes were connected to the EGG unit. The following measures were extracted from a vowel phonation (/a/).

a. Contact Quotient: It is the ratio of the duration of the contact phase (closed time) to total time.

b. Open Quotient: It is the ratio of the duration of the open phase to total time.

c. Speed Quotient: It is the ratio of the duration of opening to closing time.

c. Aerodynamic Analysis

Maximum Phonation Duration (MPD): MPD was extracted in seconds (sec) for /a/, /i/, /u/, /s/, /z/ from the phonation task recorded using a recorder. Three iterations were taken for the phonation of /a/ alone; the longest of the three trials was taken as MPD.

d. Cepstral Analysis

The cepstral analysis is a measure of acoustic analysis to quantify the fundamental frequency, and harmonic organization in voice gives various measures like Cepstral Peak Prominence (CPP) and Smoothened Cepstral Peak Prominence (sCPP). The CPP is determined by measuring the amplitude difference from the highest peak of the Cepstrum to the corresponding regression line, which is drawn directly below to the Cepstral peaks and when a smoothening factor is applied to that sCPP is obtained. For this purpose, participants were requested to sustain vowel /a/ at comfortable pitch and loudness for 3 seconds using Praat software (version). The values were then extracted with settings recommended by Maryn and Weenink (2015).

e. Self Perception of voice

Two commonly used self-rated scales developed to understand the impact of vocal loading, as perceived by the participants, were used. Further, Evaluation of the Ability to Sing

Easily (EASE; Phyland et al., 2013) was also used document the changes in the self-perception of voice during the experiment.

a. *Perceived Phonatory Effort (Sunderrajan et al., 2017)*

The Perceived Phonatory Effort (PPE) is a 9-inch visual analog scale, where participants had to rate their vocal effort anywhere between the anchors of "no vocal effort" and "maximum vocal effort." Further, the investigator completed the analysis by calculating the distance from the "no effort" anchor to the participant's rating mark, in inches.

b. *Perceived Vocal Tiredness (Sunderrajan et al., 2017)*

The Perceived Vocal Tiredness (PVT) is a 9-inch visual analog rating scale with anchors "not tired' to "tired" to assess the perceived vocal tiredness. The distance from the "not tired" anchor to the participant's marking was calculated to obtain the self-perceived vocal tiredness.

c. *Evaluation of the Ability to Sing Easily (Phyland et al., 2013)*

Evaluation of Ability to Sing Easily (EASE) was used to analyze the singers' self-perception about their vocal status after each experiment. The EASE is a validated, easy to use tool for a singer that permits a self-evaluation of the singer's vocal status developed by (Phyland et al., 2013) in English language. The questionnaire addresses two significant issues Vocal Fatigue (VF) and Pathologic Risk Indicators (PRI). Both the sections comprise of 10 questions each, with four alternatives describing each question: "not at all," "mildly," "moderately" and "extremely." Each of the alternatives is given a score of 1, 2, 3, and 4 respectively; however, three questions under VF are reverse scored (Question number: 4, 7 and 8) (Appendix 2). Each singer completed EASE by marking the appropriate alternative, based on the self-perception of their voice at that very moment. Total scores under each of the sections and the overall total was further calculated for both the days.

Experiment II- Systemic Hydration

A quasi-experimental, within-subject design was used. Each singer participated for two sessions, scheduled on two different days, which included a vocal loading task. The sessions represented no hydration (Day 1) and systemic hydration (Day 2) conditions, respectively.

3.2.1 Participants

In this experiment, twelve active Carnatic Classical singers were recruited to understand the immediate effect of systemic hydration on vocal loading. All the singers were personally contacted and explained the purpose and procedure of the study. A total of 12 active Carnatic Classical singers, two males, and ten females (11 performing artists and one music teacher) participated in the experiment. All the participants were between the age ranges of 17-35 years, with a mean age of 21.66 (SD= 3.60). Most of the participants indulged themselves in practice for 1-3 hours/day (n= 10). The singers had to meet the same inclusion and exclusion criteria as the one stated in experiment I, to be a part of the present experiment.

TABLE3. Individual Participant Characteristics for experiment 2

SL. No	Gender	Age (Years)	Music Training(Years)	Hours of singing/ day (hours)	Number of Performances/ year
1	Male	17	11-15	3-6	10-20
2	Female	20	11-15	1-3	10-20

3	Female	21	>15	1-3	>30
4	Male	23	5-10	1-3	10-20
5	Female	23	11-15	1-3	21-30
6	Female	23	>15	3-6	10-20
7	Female	23	>15	1-3	>30
8	Female	31	>15	1-3	10-20
9	Female	19	>15	1-3	<10
10	Female	18	<5	1-3	<10
11	Female	22	11-15	1-3	>30
12	Female	20	>15	1-3	<10

3.2.2 Data collection and Procedure

Initially, the Carnatic Classical singers were asked to fill a demographic questionnaire for identification of age, gender, singing experience, time of singing practice, number of hours singing/week. For the same, a simplified version of Singer's questionnaire developed by Devadas, Kumar, and Maruthy (2018) was used. All the subjects participated for two days in order to complete the experiment. On day1 (no hydration condition), participants followed the vocal loading task without the intake of any liquids in between. On day2 (systemic hydration condition), participants followed a vocal loading task along with systemic hydration. Participants completed the vocal loading task by singing for an hour in a sound-treated room. Specifically, the vocal loading task of singing in background noise (multi-talker babble at 65- 70 dB sound pressure level near the singer's ear) was included. In the no hydration condition, the participants were deprived of any liquid intake throughout one hour of singing. During the systemic hydration, condition participants were provided with 250ml of water after the first half of singing. Such a hydration schedule was stipulated based on a study in pharmacokinetic analysis, which reports that it takes 75-120 minutes for complete absorption of water in blood cells and the plasma (Péronnet et al., 2012). In both the condition, the participants refrained from any fluid (carbonated/ caffeinated drinks, tea, coffee or even any energy drinks) intake at least 1hour before the pre-test (Wyk, Cloete, Hattingh, Linde, & Geertsema, 2017).

3.2.3 Outcome measures

All the participants were evaluated before and after the vocal loading challenge for acoustic, aerodynamic, and self-rated voice measures, and identical data collection procedures were carried out for both sessions. For the same, a phonation task was carried out with appropriate instructions. The same procedures were followed out to extract the measures as experiment I. The different measures considered are as follows:

Self Perceptual voice analysis**:** Under this, Perceived Phonatory Effort (Sunderrajan et al., 2017), Perceived Vocal Tiredness (Sunderrajan et al., 2017), and Evaluation of the Ability to Sing Easily (Phyland et al., 2013) were used.

Acoustic Analysis: The Multi-Dimensional Voice Program (MDVP) software of the Computerized Speech Lab (CSL) 4500 model (KAY PENTAX, New Jersey, USA) was used for the analyses of phonation samples. Mean Fundamental Frequency (MF0), Highest Fundamental Frequency (FHi), Lowest Fundamental Frequency (Flo), Jitter (absolute jitter), Shimmer (dB) and Noise to Harmonic Ratio (NHR). Electrographic (EGG) signal was recorded for vowel /a/ using Real-Time EGG module given by CSL-4500. Measures extracted include: Contact Quotient (CQ), Open Quotient (OQ) and Speed Quotient (SQ).

Aerodynamic Analysis: Maximum Phonation Duration (MPD): MPD was extracted in seconds (sec) for /a/, /i/, /u/, /s/, /z/ from the phonation task recorded using a recorder. Three iterations were taken for the phonation of /a/ alone; the longest of the three trials was taken as MPD.

Cepstral Analysis: Measures like Cepstral Peak Prominence (CPP) and Smoothened Cepstral Peak Prominence (sCPP) were considered.

3.3 Statistical Analysis

SPSS version 20 was used for statistical analysis of the extracted data for both the experiments. Descriptive statistics were employed to find the mean, standard deviation, minimum, and maximum of the extracted measures. For both the experiments, the data followed a non- normal distribution based on the Shapiro Wilks test of normality. Thus, the non-parametric test, the Wilcoxon Signed Ranks Test, was used to understand the significance.

4. Results

The rationale behind the current project was to study the effects of vocal loading in the voice of Carnatic classical singers and subsequently investigate the impact of straw phonation and systemic hydration on the negative effects of vocal loading. All the participants completed a vocal loading task of singing continuously for an hour in the presence of background noise (multi-talker babble of 65-70dB). The study had two experiments: experiment I investigated the immediate effects of straw phonation on vocal loading and experiment II investigated the effect of systemic hydration on vocal loading in Carnatic classical singers. Each of the experiments was scheduled for two days (two sessions). The counterbalancing technique was followed for the present experimental study, where each of the two sessions represented control and experimental condition. For each experiment, pre and post every session, acoustic, aerodynamic, electroglottographic, and self –perceptual measures were obtained from the singers.

Descriptive statistics were done to find the mean and standard deviation of the dependent variables. As the sample size was small and followed a non-normal distribution, the Wilcoxon Signed Rank Test was done to check the differences in pre and post extracted measures. The effect size was calculated to measure the sizes of differences for the measures, which showed a statistically significant difference, using Cohen's *d* (Cohen, 1988).

Experiment I- Immediate effect of Straw Phonation on vocal loading in Carnatic classical singers

Twelve Carnatic Classical singers participated in two sessions defined as treatment and no treatment condition, scheduled as day one and day two, respectively. During the treatment condition, the participants followed an 8-minute straw phonation exercise.

3.1 Acoustic Measurements

Fundamental frequency and its related measures, jitter and related measures, shimmer and related measures, noise to harmonic ratio, Cepstral peak prominence, and smoothened Cepstral peak prominence were extracted from phonation samples of the singers. Descriptive statistics, Z scores, and *p* values for the extracted measures are summarized in Table 4. The results revealed no statistically significant difference ($p<0.005$) between pre and post-test scores for both treatment and no treatment condition for all the acoustic and Cepstral measures except for shimmer percent. Shimmer percent showed a significant difference with $p=0.03$ ($p<0.005$) and had a medium effect size ($d= 0.58$) on the no-treatment condition with an increase in mean value from pre to post-test (mean values; pre= 2.54, post= 2.98).

Table 4. Pre and Post mean values, standard deviation, Z, and *p* values of acoustic and Cepstral measures across treatment and no treatment conditions for experiment 1.

Parameters	**Tasks**	**Mean**		**SD**		**Z Value**	***p* Value**	**Effect size**
		Pre	Post	Pre	Post			
Mean Fundamental Frequency (MF0)	Treatment	204.36	204.16	44.95	45.98	-.47	.63	
	No Treatment	209.72	202.46	45.34	44.96	-1.72	.08	
Highest Fundamental	Treatment	209.48	210.05	45.32	45.89	-.47	.63	

Frequency (FHi)								
	No treatment	215.87	208.76	46.05	45.63	-1.80	0.71	
Lowest Fundamental Frequency (Flo)	Treatment	198.95	198.51	43.35	45.07	-.39	.69	
	No treatment	203.61	197.03	44.77	44.65	-1.41	.15	
Jitter Percent	Treatment	.67	.67	.23	.50	-1.05	.28	
	No treatment	.71	.75	.30	.58	-.43	.66	
Absolute Jitter	Treatment	35.10	41.08	15.23	50.40	-.94	.34	
	No treatment	37.61	47.90	30.59	60.15	-.07	.93	
Shimmer Percent	Treatment	2.76	2.53	.66	.84	-.70	.48	
	No treatment	2.54	2.98	.71	.78	-2.11	**.03***	**0.58**
Shimmer dB	Treatment	.23	.21	.05	0.74	-.63	.52	
	No Treatment	.21	.23	.06	.05	-1.25	.20	
Noise to Harmonic Ratio (NHR)	Treatment	.11	.11	.01	.02	-.62	.53	
	No treatment	.11	.11	.01	.01	-.10	.91	
Cepstral Peak Prominence (CPP)	Treatment	27.86	28.04	1.75	2.37	-.23	.81	
	No treatment	28.57	28.29	1.67	1.33	-.27	.78	
Smoothened Cepstral Peak Prominence (sCPP)	Treatment	17.33	17.71	1.39	2.23	-.54	.58	
	No treatment	17.73	17.77	1.38	1.18	-.07	.93	

*Significant ($p<0.05$)

3.2 Aerodynamic Measurements

The maximum phonation duration (MPD) was calculated for /a/, /i/, /u/, /s/ and /z/. The descriptive statistics and the significance level, pre, and post both the conditions are summarized in Table 5. The results of Wilcoxon Signed Rank test showed that there was no significant difference except for MPD of /a/. There was a significant difference for MPD of /a/, p=0.02

(p<0.05) with medium effect size, d=0.4, between pre and post-test, for the no-treatment condition. The mean values were noted to decrease from 13.11 in the pre-test to 11.8 in the post-test for the no-treatment condition.

Table 5. Pre and Post mean values, standard deviation, Z, and *p* values of aerodynamic measures across treatment and no treatment conditions for experiment 1.

Parameters	**Tasks**	**Mean**		**SD**		**Z Value**	***p* Value**	**Effect Size**
		Pre	Post	Pre	Post			
/a/	Treatment	12.35	12.26	2.59	4.72	-.94	.34	
	No Treatment	13.11	11.80	3.50	2.96	-2.27	**.02***	**0.40**
/i/	Treatment	13.29	12.73	4.11	4.62	-.86	.38	
	No treatment	14.00	13.38	4.59	4.69	-.94	.34	
/u/	Treatment	12.53	12.69	3.81	4.23	-.23	.81	
	No treatment	13.93	12.52	5.40	4.15	-1.41	.15	
/s/	Treatment	11.07	10.62	5.06	4.92	-1.17	.23	
	No Treatment	10.35	9.26	4.54	3.27	-.94	.34	
/z/	Treatment	12.62	12.21	3.94	3.92	-1.02	.30	
	No treatment	12.39	11.40	5.36	3.90	-1.49	.13	

*Significant (p<0.05)

3.3 Electroglottographic Measurements

Descriptive statistics, Z, and the p values for different electroglottographic measures such as the contact quotient, open quotient, and speed quotient are summarized in Table 6. None of the EGG measures showed a significant difference (p > 0.05) across pre and post-test on both treatment and no treatment conditions.

Table 6. Pre and Post mean values, standard deviation, Z, and *p* values of aerodynamic measures across treatment and no treatment conditions for experiment 1.

Parameters	**Tasks**	**Mean**		**SD**		**Z Value**	***p* Value**
		Pre	Post	Pre	Post		
Contact Quotient	Treatment	44.25	43.42	3.15	4.03	-.39	.69
	No Treatment	44.62	44.29	2.77	2.89	-.47	.63
Open Quotient	Treatment	55.74	56.57	3.15	4.03	-.39	.69
	No treatment	55.41	55.61	2.76	2.75	-.31	.75
Speed Quotient	Treatment	251.38	276.36	62.65	81.70	-1.56	.11
	No treatment	256.88	262.60	50.28	69.01	-.23	.81

3.4 Self- Perceptual Measurements

Under self perceptual measurements, three scales were considered- Perceived Vocal Tiredness (PVT), Perceived Phonatory Effort (PPE), and the Evaluation of the Ability to Sing Easily (EASE). The mean value, standard deviation, Z value, and *the p* value of the three self-perceptual measures for both treatment and no treatment conditions were are shown in Table 7. The results showed a significant difference ($p<0.05$) between the pre-test versus post-test scores for both- treatment and no treatment condition, for PVT (no treatment $p=0.02$ and treatment $p=0.01$) and PPE (no treatment $p=0.01$ & treatment $p=0.02$). During the treatment condition, both PVT and PPE had large effect size ($d=0.7$ & $d=0.63$). For the no-treatment condition, PVT had a medium effect size (*d* =0.56), and PPE had a large effect size (*d*=0.67). EASE showed significant difference only for no treatment condition (*p*=0.00, p<0.05) with a large effect size (d=0.90). Overall, with a significant difference, the mean values increased from the pre-test versus post-test for PVT and PPE for both the conditions. While for EASE, mean values increased between pre-test and post-test for no treatment condition alone.

Table 7. Pre and Post mean values, standard deviation, Z, and *p* values of self- perceptual measures across treatment and no treatment conditions for experiment 1.

Parameters	**Tasks**	**Mean**		**SD**		**Z Value**	***p* Value**	**Effect Size**
		Pre	Post	Pre	Post			
PVT	Treatment	1.68	2.67	1.25	1.55	-2.58	**0.01***	**0.70**
	No Treatment	2.58	3.62	1.40	2.17	-2.27	**0.02***	**0.56**
PPE	Treatment	1.81	2.72	1.26	1.59	-2.19	**0.02***	**0.63**
	No treatment	2.26	3.42	1.51	1.92	-2.51	**0.01***	**0.67**
EASE	Treatment	30.16	32.41	5.49	5.82	-1.24	.21	
	No treatment	33.0	39.16	6.33	7.28	-2.82	**0.00***	**0.90**

*Significant (*p*<0.05)

Thus from this experiment, it was observed that, without straw phonation, shimmer percent, EASE, and MPD of /a/ increased with vocal loading between pre-test versus post-test. With and without straw phonation, PPE and PVT values increased between pre-test versus post-test.

Experiment II- Effect of Systemic Hydration on vocal loading in Carnatic classical singers

Twelve Carnatic Classical singers participated in two sessions defined as no hydration and systemic hydration condition, scheduled as day one and day two, respectively. During both the days, the participants followed the vocal loading; however, only during systemic hydration condition, the participants were allowed to have 250ml of water after 30 minutes of signing. As the sample size was small, and had non-normal distribution, the Wilcoxon Signed Rank test was done to check the differences in pre and post-test across both conditions.

3.5 *Acoustic Measurements*

The mean value, standard deviation, *p* value, and the z value for all the extracted acoustic and Cepstral measures are presented in Table 8. There was no significant difference ($p > 0.05$) across the acoustic and Cepstral measures between pre versus post-test, for both the conditions (systemic hydration and no hydration).

Table 8. Pre and Post mean values, standard deviation, Z, and *p* values of acoustic and Cepstral measures across no hydration and systemic hydration conditions for experiment 2.

Parameters	**Tasks**	**Mean**		**SD**		**Z Value**	***p* Value**
		Pre	Post	Pre	Post		
Mean Fundamental Frequency (MF0)	No Hydration	213.70	223.05	49.00	42.82	-1.88	.06
	Systemic hydration	220.56	221.92	51.57	48.44	-.15	.87
Highest Fundamental Frequency (FHi)	No Hydration	219.14	228.17	50.70	43.87	-1.72	.08
	Systemic hydration	226.53	227.10	53.44	49.98	-.31	.75
Lowest Fundamental Frequency (Flo)	No Hydration	209.08	216.93	47.82	41.32	-1.56	.11
	Systemic hydration	215.02	216.93	49.96	48.41	-.15	.87
Jitter Percent	No Hydration	.60	.71	.51	.50	-.74	.45
	Systemic hydration	.76	.59	.52	.54	-.78	.43
Absolute Jitter	No Hydration	29.28	32.67	21.51	21.26	-.62	.53
	Systemic	35.14	26.31	22.10	25.23	-1.49	.13

	hydration						
Shimmer Percent	No Hydration	2.47	2.63	.51	.62	-.78	.43
	Systemic hydration	3.44	2.77	2.62	1.27	-.54	.58
Shimmer dB	No Hydration	.21	.22	.04	.05	-.81	.41
	Systemic hydration	.33	.25	.35	.11	-.17	.85
Noise to Harmonic Ratio (NHR)	No Hydration	.10	.10	.01	.03	-.41	.67
	Systemic hydration	.12	.11	.00	.02	-.56	.57
Cepstral Peak Prominence (CPP)	No Hydration	27.81	28.05	2.89	2.47	-.47	.63
	Systemic hydration	26.92	26.95	2.98	2.18	-.54	.58
Smoothened Cepstral Peak Prominence (sCPP)	No Hydration	17.36	17.18	1.92	1.85	-.23	.81
	Systemic hydration	16.54	16.71	2.14	1.80	-.62	.53

3.6 Aerodynamic Measurements

Table 9 summarizes the descriptive statistics, Z value and *p* value of the maximum phonation duration of /a/, /i/,/u/, /s/ and /z/, across different conditions, between pre-test versus post-test. There was no significant difference (p > 0.05) noted across the conditions between pre versus post-test values.

Table 9. Pre and Post mean values, standard deviation, Z, and *p* values of aerodynamic measures across no hydration and systemic hydration conditions for experiment 2.

Parameters	**Tasks**	**Mean**		**SD**		**Z Value**	***p* Value**
		Pre	Post	Pre	Post		
/a/	No hydration	14.32	13.55	3.13	4.20	-.94	.34
	Systemic Hydration	14.07	15.90	4.15	6.41	-1.25	.20
/i/	No hydration	14.60	15.07	3.86	5.35	-.54	.58
	Systemic	14.19	15.65	3.60	6.22	-1.33	.18

	Hydration						
/u/	No hydration	14.46	15.03	3.67	5.48	-.07	.93
	Systemic Hydration	13.71	14.78	3.72	4.59	-1.72	.08
/s/	No hydration	11.11	10.33	3.61	2.73	-.94	.34
	Systemic Hydration	9.85	9.40	3.16	2.51	-.62	.53
/z/	No hydration	11.83	12.06	3.69	4.22	-.17	.85
	Systemic Hydration	11.38	11.71	3.87	3.83	-.23	.81

3.7 Electroglottographic Measurements

Electroglottographic measures such as contact quotient, open quotient, and speed quotient values were obtained using steady phonation of /a/. The mean value, standard deviation, Z value, and *p* values for the three EGG measures were obtained for both no hydration and systemic hydration condition (Table 10). The results of the Wilcoxon signed Rank Test revealed statistically no significant difference ($p > 0.05$) between pre versus post-test values.

Table 10. Pre and Post mean values, standard deviation, Z, and *p* values of self- perceptual measures across no hydration and systemic hydration conditions for experiment 2.

Parameters	**Tasks**	**Mean**		**SD**		**Z Value**	***p* Value**
		Pre	Post	Pre	Post		
Contact Quotient	Treatment	34.52	33.15	20.86	20.25	-1.59	.11
	No Treatment	32.99	32.68	19.99	19.86	-.65	.51
Open Quotient	Treatment	40.46	41.77	24.43	25.41	-1.36	.17
	No treatment	42.00	42.26	25.40	25.59	-.65	.51
Speed Quotient	Treatment	244.20	228.25	161.34	145.24	-.77	.44
	No treatment	216.53	220.56	150.27	139.46	-.17	.85

3.8 Self- Perceptual Measurements

Three self-perceptual measures, Perceived Vocal Tiredness (PVT), Perceived Phonatory Effort (PPE), and the Evaluation of the Ability to Sing Easily (EASE), were used. Table 11 shows the mean, standard deviation, Z value, and *p* value of the self –perceptual measures for both no hydration and systemic hydration conditions. There was a significant difference ($p<0.05$) between the pre-test versus post-test scores for all three measures PVT, PPE, and EASE for the no hydration condition with $p=0.01$, $p=0.03$ *and* $p=0.01$ respectively. All the three measures had a large effect size (PVT: $d=1$, PPE: $d=0.83$, EASE: $d=0.77$). PVT and PPE also showed a significant difference ($p<0.05$) between pre-test and post-test for systemic hydration with $p=0.02$ $p=0.04$, respectively. Both PVT and PPE showed a medium effect size with $d=0.67$ and $d=0.61$, respectively.

Table 11. Pre and Post mean values, standard deviation, Z, and *p* values of self- perceptual measures across no hydration and systemic hydration condition for experiment 2.

Parameters	**Tasks**	**Mean**		**SD**		**Z Value**	***p* Value**	**Effect size**
		Pre	Post	Pre	Post			
PVT	No hydration	1.49	2.93	.89	1.83	-2.51	**.01***	**1.00**
	Systemic Hydration	1.02	1.86	.76	1.59	-2.19	**.02***	**0.67**
PPE	No hydration	1.25	2.41	.74	1.81	-2.08	**.03***	**0.83**
	Systemic Hydration	1.18	2.09	1.04	1.82	-2.00	**.04***	**0.61**
EASE	No hydration	27.41	32.41	4.25	8.03	-2.49	**.01***	**0.77**
	Systemic Hydration	25.33	28.00	3.67	5.46	-1.42	.15	

*Significant difference ($p<0.05$)

Thus from this experiment, it was observed that PPE and PVT values increased post vocal loading on both, no hydration and systemic hydration condition. While EASE scores increased post vocal loading in no hydration condition alone. None of the acoustic, aerodynamic, and electroglottographic measures showed a significant difference across both the conditions.

5. Discussion

Individuals using their voice as an occupational instrument are at a higher risk of developing voice problems as their vocal use is more frequent and could be exhausting at times (Kaufman & Blalock, 1988). In the past, several attempts have been made to understand the anatomical and physiological changes that happen in the larynx after prolonged and consistent usage of voice-based vocal loadings tasks. Vocal loading tasks refer to the voice task rather than a compromised state of the larynx.

The present study investigated the effects of straw phonation and systemic hydration on vocal loading in Carnatic classical singers. Clinically such a study is relevant as singers are often exposed to the environment where they engage themselves in vocal loading activities such as prolonged singing in the presence of background noise. The study had two experiments: experiments I and II were incorporated to investigate the immediate effects of straw phonation and systemic hydration, respectively, on vocal loading in Carnatic classical singers. A total of 24 Carnatic Classical singers, 12 in each experiment, participated in the present study. All the participants completed a vocal loading task of singing continuously for an hour in the presence of background noise (multi-talker babble of 65-70dB). Each of the experiments was scheduled for two days (two sessions). The counterbalancing technique was followed for the present experimental study, where each of the two sessions represented control and experimental condition.

For the experiment I, the results revealed that acoustic measures like shimmer percent, self-perceptual measures like PVT, PPE, EASE, and aerodynamic measure: MPD /a/, showed a significant difference between pre-test and post-test of a vocal loading task. While for experiment II, only self-perceptual measures like PPE, PVT, and EASE showed significant differences before and after vocal loading tasks. Across both the experiments, self-perceptual measures: Perceived Vocal Tiredness (PVT), Perceived Phonatory Effort (PPE), and Evaluation of the Ability to Sing Easily (EASE) showed a significant difference before and after the vocal loading task.

PPE, self-rated vocal discomfort and fatigue are considered to be a significant measures sensitive to vocal loading (Enflo, Sundberg & Mc Allister, 2013; Kelchner, Lee & Stemple, 2003; Chang & Karnell, 2004; Sodersten, Ternstrom & Bohman, 2005; Gorham-Rowan, Berndt, Carter & Morris, 2016). PPE is reported to increase after as little as 20-30 minutes of vocal loading task (Enflo, Sundberg & Mc Allister, 2013; Sodersten, Ternstrom & Bohman, 2005). PPE was observed to increase after a vocal loading task in almost all the studies examined in a review study done on vocal loading (Fujiki & Sivasankar, 2017). A similar trend was also found in an unpublished study done on vocal loading among Carnatic classical singers (Amrutha, 2019). The authors concluded no significant effect of vocal loading on acoustic measures like fundamental frequency, shimmer, jitter, cepstral peak prominence, smoothened cepstral peak prominence were found. However, self- perceptual measures like PVT and PPE significantly increased after the vocal loading task, thus supporting the results of the present study. Despite PPE being sensitive to laryngeal changes following vocal loading task, literature does not have evidence of how much of this could be correlated with aerodynamic and acoustic voice measures (Whitling, Rydell & Ahlander, 2015). Further, all the participants showed a significant increase in EASE scores across both Vocal Fatigue and Pathologic Risk Indicator sub-sections. This could again be attributed to the perceptual fatigue the singers face as a result of the vocal loading task.

Comparing the present study with a study done by Yiu et al. (2013) on vocal loading, few observations could be drawn. In their study, they considered, a vocal loading task of karaoke singing above 80dB in the presence of ambient music of 60dB, on ten male and female singers. The results revealed that there was an increase in self-rated effort of voicing while objective measures like fundamental frequency, intensity, speed quotient, and open quotient remained the same before and after singing. It was found that the mean values of self- rated effort in voicing increased from 0.55 (pre-singing) to 6.95 (post-singing). PPE values increased from 2.53 (pre-test) to 3.44 (post-test) with vocal loading in the present study. When we compare the descriptive values across both the studies, the present study showed a lesser increase in mean scores. Such a difference could be related to the difference in the singing style of the participants. The Carnatic singing style known for its intensive training could be an advantage over karaoke singing. In other words, trained singers tend to adjust laryngeal mechanisms to an unfamiliar task in a more economical manner, while singers with limited laryngeal control might tend to develop more of a muscle tension instead.

Concerning the effect of vocal loading on different voice measures, some conclusions could be narrowed down from the literature, which agrees with the present study. A study done by Buekers (1998) concluded no change in electroglottographic values and NHR after a vocal loading task. Considering the cepstral measures, the sensitivity of cepstral peak prominence and smoothened cepstral peak prominence on vocal loading induced changes is yet to be explored in depth. However, Gorham- Rowan et al. (2016) carried a vocal loading task in seven healthy adults and concluded that there was no significant effect of vocal loading on the measures- NHR, CPP, and F0. Previous authors have also noted parameters like jitter, shimmer (Verstraete, Forrez, Mertens, & Debruyne, 1993) to have limited sensitivity to laryngeal changes, induced as a result of vocal loading task. Studies have also shown no change in the individuals' F0 with vocal loading tasks (De Bodt at el, 1998; Neils & Yairi, 1987).

Studies have concluded that vocally demanding tasks using solely elevated intensity should likely be 1hour or greater in duration to produce considerable laryngeal changes, task shorter than have generally not produced much difference in objective measures other than on patient-perceived measures (Fujiki & Sivasankar, 2017). Considering this, in the present study, one hour of continuous singing in the presence of 65-70dBSPL was considered with the notion that, a minimum of one hour of singing is essential to bring a vocal load as Carnatic classical singers are usually exposed to singing for >1 hour in the presence of instrumental noise. Though the vocal loading tasks was capable of generating vocal tiredness and phonatory effort among singers in the present study, physiologically, no significant difference was made, because of which none of the acoustic, cepstral, and electroglottographic measures were affected.

In discussion with participants, the majority of the singers stated that one hour of singing does not vocally load them to a great extent as they are trained to sing for hours together for concerts, in the presence of instrumental noise without any voice rest in between. Carnatic classical singers sing in a graded manner that they do not strain their voice and maintains optimum energy throughout the concert. Any classical music is initiated with a Varnam in the beginning and Pallavi at the intervening stage, which is a repetition of any Kriti or keerthana, which are more strenuous and demands significant effort. In the future, vocal loading producing a measurable change in voice could be generated by manipulating the vocal loading task to a more significant duration, in the presence of a much higher level of background noise and with the inclusion of other variables.

5. 1 Immediate effects of straw phonation on vocal loading in Carnatic classical singers

This objective was taken up to understand whether negative laryngeal functions developed as a result of vocal loading could be changed when engaged in straw phonation, a semi- occluded vocal tract exercise. Straw phonation is one among the SOVTEs (Titze, 2001); it is known to optimize the facial vibration sensations resulting from increased intraoral acoustic pressure. Doing so helps individuals optimally adjust their vocal tract to improve vocal performances (Titze & Laukkanen, 2007).

The results revealed that, with straw phonation, self-rated measures PVT and PPE showed a significant difference before and after vocal loading. All other acoustic, electroglottographic, aerodynamic, and cepstral measures did not show statistically significant differences across pre-test and post-test scores of vocal loading task. This could be attributed to the various benefits of straw phonation as a relaxation exercise. With straw phonation, the vertical laryngeal position is known to lower, which is considered to reduce muscle tension (Wistbacka, Sundberg, & Simberg, 2016). Through straw phonation, bubbles are produced at the surface of the water; this, in turn, generates a pulsating oral pressure, which could probably act as a massage to the laryngeal and pharyngeal tissues (Guzman et al., 2017). Also, semi-occluded vocal tract exercises (straw phonation being one among the exercises) are known to reduce collision impact between the vocal folds during vibration and are economic vocal exercises

(Titze, 2002). To the best of our knowledge, this is probably the first study that has looked into the immediate effect of straw phonation on vocal loading. Positive effects of straw phonation exercise could thus be used to educate Carnatic classical singers, who are engaged in singing for concerts, which itself is a vocally demanding task.

5.2 Effect of systemic hydration on vocal loading in Carnatic classical singers

Hydration is one of the most frequently used strategies to restore vocal function or quality (Yiu & Chan, 2003) and claim to have a positive impact on voice (Franca & Simpson, 2009) Solomon & Di Matti (2000) carried a study in four women with healthy untrained voices to examine the changes in laryngeal function after prolonged loud reading, and to examine how these changes vary with drinking water. The results revealed that the phonation threshold pressure at a high pressure increased after prolonged loud reading, and this effect was found to be attenuated by drinking water in three of the four speakers. Systemic hydration could thus calm the negative phonatory effects of vocal loading. Similar studies in the Indian context could serve as educational information for Carnatic classical singers for the everyday practices of encouraging increased water consumption.

The second objective was to study the immediate effects of systemic hydration on vocal loading. The experiment was scheduled for two days, where day-1 followed a no-hydration, and day-2 followed a systemic hydration schedule. On both, the day's participants followed a vocal loading task of continuous singing for one hour in the presence of background noise. The results of the experiment revealed that PPE and PVT values increased post vocal loading on both, no hydration and systemic hydration condition. While EASE scores increased post vocal loading in no hydration condition alone. None of the acoustic, aerodynamic, and electroglottographic measures showed a significant difference across both the conditions.

Most of the participants reported dry throat following the vocal loading task, which was reflected as an increase in scores of self- perceptual measures, though perceptually no difference in voice quality was noticed to the experimenter. This could be attributed to the fact that systemic dehydration is thought to be reflected in the vocal fold mucosa, increasing its viscosity and reducing mucosa mobility (Verdolini-Marston, Sandage, & Titze, 1994; Verdolini-Marston, Titze, & Druker, 1990). Yiu and Chan (2003) found that the perceptual and acoustic measures, and vocal function, did not show any significant change during intensive karaoke singing in the subjects who were given water and rest during the singing. However, subjects who sang continuously without drinking water and taking rests showed significant changes in the jitter measure and the highest pitch they could produce during singing. The results of the present study also followed a similar pattern for the systemic hydration condition, but the trend was not the same for no hydration condition as none of the acoustic and aerodynamic changes were observed in voice in no hydration condition.

From a systematic review on the effect of hydration on voice quality in adults, significant negative effects of fasting and not ingesting fluids on parameters like NHR, jitter, shimmer, and F0 were quoted. Also, water ingestion is known to bring significant improvement in shimmer, jitter, F0, and maximum phonation time values (Alves, Krüger, Pillay, Lierde, & Linde, 2017). One possible reason for the limited difference in measures in the present study could be because of the difference in vocal loading task that was utilized and the type of singing style considered. Probably a hard vocally demanding task incorporating multiple variables (in terms of duration, ambient noise) might show a significant difference across acoustic, aerodynamic, and electroglottographic measures. The amount of water intake considered in the present study was 250ml after 30 minutes of singing, which could also be a contributing factor to limited differences in measures. Probably the brief period of water intake did not bring a significant effect on vocal function, as concluded in a study done by Gorham-Rowan, Berndt, Carter, and Morris (2016).

Overall no significant changes in acoustic, aerodynamic, and electroglottographic measures in Carnatic classical singers after the vocal loading task could be related to various benefits of the Carnatic singing style. This includes more significant breath support while singing, use of beneficial signing practices like loud, open-throated, predominantly low-pitched singing embedded with vocal nuances at higher pitches (Arunachalam, Boominathan, & Mahalingam, 2014), which in turn could limit the strain in their voice even when they're to sing for a prolonged period. In other words, the larynx is probably robust to withstand a one-hour vocal loading task and the habitual vibratory patterns associated with it, even in the presence of background noise.

Limitations and Future directions

Though self-perceptual measures alone showed significant differences with vocal loading, straw phonation exercise, and systemic hydration, no definite conclusions could be drawn secondary to the small sample size. Thus, the results of the present study need to be strengthened with a larger sample size, preferably with equal distribution of male and female Carnatic classical singers. Further, the vocally loading task design considering various variables increased the duration, and ambient noise should be considered for future studies. Studies investigating the effects of vocal loading in other Indian singing styles should also be looked at in the future. While considering systemic hydration, it probably increased the amount, and frequent intake should be considered.

VII. Summary and Conclusion

To the best of our knowledge, no significant studies are carried out to understand the immediate effect of straw phonation and systemic hydration on vocal loading in Carnatic classical singers. Our overarching goal was to enrich the scientific literature by investigating the negative effects of vocal loading in Carnatic classical singers and how it could be overcome through straw phonation exercise and systemic hydration. A total of 12 active Carnatic classical singers participated in each of the experiments. For the experiment I, participants practiced straw phonation before the vocal loading task for the treatment condition. On the no-treatment condition, participants were indulged only in the vocal loading task. For the experiment I, for no-hydration condition singers participated in a vocal loading task while for systemic hydration condition, 250ml of water was given after half an hour of vocal loading task. For both the experiments, a vocal loading task of singing continuously for an hour in the presence of a multi-talker babble at 65-70 dB SPL was designed. The results of the present study revealed that self-perceptual measures like PVT, PPE, and EASE showed a significant difference with the vocal loading task. With straw phonation and systemic hydration, self-rated measures PVT and PPE showed a significant difference before and after vocal loading. Self- perceptual measures might thus act as a good indicator of vocal loading.

However, the evidence of the present study needs to be strengthened with larger sample size and across different vocal loading tasks. This study lays the groundwork for further investigation that could highlight the trends seen in other Indian singing styles.

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Appendix

1. GRBAS (Taken from Hirano, M., 1981, Clinical Examination of the Voice)

Perceptual Quality	Description	Rating Scale
G Grade	Degree of Hoarseness of the voice	0 = Normal 1 = Slight 2 = Moderate 3 = Severe
R Roughness	Impression of the irregularity of vocal fold movement	
B Breathiness	Degree of escaping air heard	
A Asthenia	Degree of weakness	
S Strain	Degree of strain or hyperfunction	

2. Evaluation of the Ability to Sing Easily (EASE)- Phyland et al. (2013)

Items	Not at All	Mildly	Moderately	Extremely
Factor 1				
My voice is husky				
My voice is dry/ scratchy				
My throat muscles are feeling overworked				
My voice feels good*				
My top notes are breathy				
The onsets of my notes are delayed or breathy				
My voice sounds rich and resonant*				
My voice is ready for performance if required*				
My voice is tired				
My voice is worse than usual				
Factor 2				
My voice cracks and breaks				
My voice is breathy				
I am having difficulty with my breath for long phrases				
My voice is cutting out on some notes				
I am having difficulty changing registers				
Today I am having difficulty with my high notes				
I am having difficulty singing softly				
Singing is hard work				
I am having difficulty sustaining long notes				

*Reverse scored