# EFFECT OF COGNITIVE LOAD ON VOICE CHARACTERISTICS IN YOUNG ADULTS

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May, 2016

## CERTIFICATE

This is to certify that this dissertation entitled **"Effect of cognitive load on voice characteristics in young adults"** is a bonafide work submitted in part fulfilment for degree of Master of Science (Speech-Language Pathology) of the student Registration Number: 14SLP032. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore

May, 2016

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## CERTIFICATE

This is to certify that this dissertation entitled **"Effect of cognitive load on voice characteristics in young adults"** has been prepared under my supervision and guidance. It is also been certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore
May, 2016

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## DECLARATION

This is to certify that this dissertation entitled **"Effect of cognitive load on voice characteristics in young adults"** is the result of my own study under the guidance of Dr. K. Yeshoda, Reader and Head, Department of Speech Language Sciences, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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May, 2016

*Dedicated to my maa, dad*

*and Krishna thatha*

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*That light at the end of the tunnel, which holds your gaze!*
*That light which motivates and encourages you!*
*That light which embarrasses you giving hopes!*
*That light like a holy grail giving you greater joy!*
*That light which is still a mystery that keeps you sailing it!*
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# CHAPTER I

"*Voice is the deepest reflection of your mind, your heart, your soul*" *(Rosoff, 1956)*

## INTRODUCTION

Human voices reveal immense information about the speaker's age (Ptacek and Sander, 1966; Shipp, Huntley, and Hollien, 1992; Cerrato, Falcone and Paoloni, 2000), state of general health (Ramig and Ringel, 1983; LaGasse, Neal and Lester, 2005), body size (Lass, DiCola, Beverly, Barbera, Henry and Badali, 1979; Krauss, Freyberg and Morsella, 2002), gender (Lass, Almero, Jordan and Walsh, 1980; Cerrato, Falcone and Paoloni, 2000) and also physiologic and psychologic state of the speaker. The underlying etiology of voice change and its overt manifestations are of great importance in the field of vocal pathology, professional voice use, forensics, aerospace medical research and basic voice science. In this regard there have been several researches attempting to study these manifestations by inducing or analyzing change in voice through varied conditions such as cognitive load, stage fright, performance anxiety, fatigue, depression-dejection, and laboratory induced neuro-humoral stress etc.

### Cognitive load (CL)

The notion of cognitive load is acknowledged as a dynamic factor in the performance efficiency of an individual in any task which varies by either underload or overload. This deterioration in performance can be attributed to task demands that surpass the available human cognitive capacity and may lead to deficient distribution of cognitive resources. This cognitive capacity while performing a task is also determined by individual’s attention resources and working memory resources which are relatively limited. Working memory is a large system that encompasses two modalities: i) visuo-spatial sketchpad, ii) phonological loop, which are coordinated by a central executive. It is clearly evidenced by researchers that working memory is limited to process only seven new elements or information at a time (Miller, 1994; Baddeley, 1992). Furthermore, when such new information is used to organize, contrast, compare or work on, it merely allows only two or three items of information to be processed simultaneously (Sweller, Merriënboer, and Pass, 1998)

*Cognitive load* can be defined as a multidimensional construct representing the load that a particular task imposes on the learner’s cognitive system while performing (Paas and Merriënboer, 1994). Sheridan and Stassen, (1979) defined cognitive workload as the information processing load placed on the individual while performing a specific task. Few other authors suggest cognitive load as an indicator of pressure on working memory during the task performance (Yin and Chen, 2007); and the level of perceived effort analogous to learning, thinking, reasoning and performing; and the available ‘space’ in human working memory resource relative to the ‘space’ required by a user to efficiently perform the task (Mousavi, Low, and Sweller, 1995). Since the available capacity of human working memory resource is limited, it results in the cognitive load which has to be monitored below a safe threshold to prevent instances of failure while performing the task.

According to the model proposed by Paas and Merriënboer (1994), the cognitive load construct is assumed to comprise two dimensions-

*a.* Causal dimension that reflects the interaction between the *task and the performer characteristics,*

*b.* Assessment dimension that reflects the measurable concepts of *mental load, mental effort, and performance.*

*Task characteristics* that have been often encountered in cognitive load research are task format, task complexity, use of multimedia, time pressure, and pacing of instruction. Intense time pressure often initializes many cognitive processes simultaneously and puts limited working memory resources at stake. *Performer characteristics* comprise expertise (e.g. cognitive abilities), age and visuo-spatial ability. Some interactions have been found in the previous researches related to age and task format, which indicate elderly individuals' performances depend on the type of task (goal-free/goal-specific) involved (Pass, Camp, Rikers, 2001); to expertise level and task format, indicating that there is a positive correlation between performance efficiency and expertise level (Kalyuga, Ayres, Chandler and Sweller, 2003); and to visuo-spatial ability and use of multimedia, indicate that individuals who have high visuo-spatial ability have an advantage when visual stimuli are used (Mayer and Moreno, 2003). Lively, Pisoni, and Summers, (1993) also stated in their study that cognitive workload increases with task difficulty. Similarly, few studies have illustrated the effects of the surrounding physical environment on cognitive task performance. For e.g., a computer-based task in a computer lab, reflects its physical properties such as the background color in the monitor screen, the type of furniture used by the subject, and even the physical properties of the computer lab and plays a role in induction of cognitive load. Conclusively they state that the environment and physical properties can also be attributed as causal dimension of cognitive load.

Focusing on elements of assessment dimension- *mental load, mental effort, and performance* are the three measurable dimensions of CL. *Mental load* is a facet of cognitive load that arises from the interaction between task and subject characteristics. According to Paas and Merriënboer' (1994), mental load can be determined on the basis of subject's characteristics and his/her contemporary knowledge about the task. It is also presumed to provide the prior estimation of expected cognitive capacity demands and resultant cognitive load. *Mental effort* is a facet of cognitive load that refers to the cognitive capacity that has been allocated to accommodate the performance demands; thus, it can be considered to replicate the actual cognitive load level. Mental effort is measured online during the ongoing task. *Performance* is also a facet of cognitive load which can be defined in terms of subject's achievements that can be measured through the number of correct responses, number of errors, and reaction time, etc. It can be estimated when the subject is working on the task or thereafter. Both causal and assessment factors affect CL (Paas and  Merriënboer, 1994).

Cognitive load theory put forth by Sweller, et al., (1998) enumerates three types of sources of cognitive load:

i. Intrinsic cognitive load is related to the inherent difficulty of tasks
ii. Extraneous cognitive load is related to the instructional or presenting method
iii. Germane cognitive load is related to the efforts devoted to learning

However, the capacity of working memory varies from individual to individual and therefore different subjects show varied manifestations of cognitive load on the same task. Working memory load is often affected by the inherent nature of the test stimuli (intrinsic CL) and by the manner of the instruction (extraneous and germane CL). For e.g. a high-complex task places the subject at higher intrinsic load than a low-complex task. Intrinsic, extraneous, and germane CL are summative and affect the performance efficiency if the total cognitive load of the three together exceeds the working memory capacity. Teigen (1994) stated that performance deteriorates at the extremes of CL level (underload and overload conditions). It is generally accepted that individuals experience high cognitive load in complex, time-pressure, and data-intense situations due to the complexity level of the task being performed which interferes with individual’s ability to perform at the optimum level.

**Measurement of Cognitive load**

Cognitive load measurement is often based on mental effort and performance measures and gives insight into understanding the relative mental efficiency of the performer in different conditions or load levels. There are several measurement techniques that have been used in cognitive load research. These measurement techniques are based on the source of indicators and they can be categorized as-

a. Analytical techniques
b. Behavioral measurement
c. Subjective measurement
d. Physiological techniques

Analytical techniques generally rely on experts’ judgement, mathematical models, and task analysis. However, behavioral measurements encompass techniques such as measuring linguistic index and observation of changes in behavior of the performer.

Subjective measurements such as self-report utilizing Rating Scale Mental Effort (RSME) or NASA Task Load Index (NASA-TLX) remain gold standard procedures till date. Physiological techniques are used in measurement of cognitive load with the knowledge that changes in cognitive functioning are reflected by physiological variables such as- Eye movement, Electroencephalogram, Event Related Potential (ERP), heart rate, Positron Emission Tomography (PET), Magnetic Resonance Imaging (MRI), blood pressure and performance. Endocrinal responses often require invasive methods in cognitive load monitoring but also many body functions, like pupil dilation and eye blink frequency, electroencephalography (EEG) responses (Hankins and Williams, 1998) skin conductance responses (Schneider, Enne, Cecon, Diendorfer-Radner, Wittels, Bigenzahn, Johannes, 2006) changes in heart rate (Sirevaag, Kramer, Wickens, Reisweber, Strayer, and Grenell, 1993; Ylonen, Lyytinen, Leino, Leppa¨luoto, and Kuronen, 1997; Hannula, Huttunen, Koskelo, Laitinen, and Leino, 2008) and hormone secretion (Otsuka, Onozawa, and Miyamoto, 2006) have been monitored to non-invasively measure the effects of cognitive load. Autonomic nervous system in turn affects the rate of breathing, voice, and speech.

Paas and Merriënboer (1994) found physiological measures except heart-rate variability to be highly sensitive in cognitive load measurement. Beatty and Lucero-Wagoner (2000) reported increase in task-evoked pupillary responses (TEPRs) as a function of cognitive load. Gerven, Paas, Merriënboer, and Schmidt (2002) found that mean pupil dilation is the most sensitive measure in young adults than older individuals. Zarjam, Epps, and Chen, (2010) investigated EEG signal recordings of five participants and found that frontal EEG signals consistently showed a very high degree of sensitivity to the subtle changes in cognitive load induced through different levels of difficulty. Thus authors inferred EEG as an important method for the real time and objective determination of cognitive load level.

The perfect measurement should be accurate, precise, non-intrusive, objective and real time which is provided by Speech based measurements. They are characteristic of the following:

a. Non-intrusive
b. Easy to measure
c. Can potentially be real time

One such speech based measurement by Steeneken and Hansen (1999) showed the following physiological changes as a result of induced cognitive load: increased respiration rate, irregular breathing, and increase in muscle tension of the vocal cords. These findings support the assumption that cognitive load results in changes happening at the level of every speech subsystem (respiration, phonation and articulation) including voice. Influences of cognitive load have also been reported on other aspects of speech such as, disfluencies, articulation rate and accuracy, quality of the content, no of syllables, no of silent pauses, no of filled pauses, sentence fragments, average length of pauses, average frequency of pause, and average response latency (Yin, ruiz, Chen, Khawaja, 2007). Neuro-physiological studies are in line with the hypothesis that speech-based measurements are good correlates of cognitive load levels. For example, studies have found that the brain region responsible for speech production gets activated when subjects perform cognitive load tasks (Paulesu, Frith, Frackowiak, 1993; Harmony, Pereyra, Bosch, and Sosa, 1999). Speech that is produced under a high cognitive load is often characterized by a faster rate of speech. A faster speech rate is often related to less intelligibility, as accurate articulation is compromised since it requires precise coordination between numerous muscle groups which is difficult to maintain under intense time pressure. According to results obtained by Mendoza and Carballo (1998), cognitive workload resulted in an increase in Fundamental frequency (F0), decrease in Pitch perturbation quotient (PPQ) and Amplitude perturbation quotient (APQ). In line with these findings, Rothkrantz, Wiggers, van Wees, and van Vark, (2004) also found consistent increase in F0 and decrease in jitter ratio while analyzing vocal parameters using modified Stroop test with time pressure. In addition, many experiments carried out with cognitive tasks have revealed increase in F0, word duration and average amplitude. Some studies also report increase in spectral energy spread, increases in the first four formants (Boril, Sadjadi, Kleinschmidt, Hansen, 2010), decreases in the second formant as a function of cognitive load (Yap, Epps, Ambikairajah, and Choi, 2011). Lively, Pisoni, Van Summers, and Bernacki, (1993) found that in cognitive load conditions subject's amplitude and amplitude variability increased and F0 variability decreased. Whereas, Fuller, Horii, Conner, (1992) reported the absence of consistency in F0 changes with respect to cognitive load tasks.

Furthermore, studies have also reported gender differences in physiologic states in response to cognitive loading but there still remain inconsistencies owing to contradictory findings and paucity of precise information of what happens to voice quality when subjected to cognitive load and its objective and quantifiable documentation is also deficient. In this regard, the present study was planned to investigate effects of cognitive load on voice characteristics to address the general notion that cognitive demands have increased in the present lifestyle as multi-tasking is the need of the hour. Moreover, many professional voice users report deleterious vocal symptoms during performances which demand higher quality, clarity, diction that requires more attention and mental effort. These effects may be attributed to increase in cognitive loading which may have detrimental effects on their voice and the same may go unnoticed. Thus it should be feasible to establish a subject's endurance to the amount of cognitive load by analyzing his/her voice quality using induction methods. This will shed light on the intrinsic factors that may govern the voice characteristics. It would also help us to gain insight on possibility of cognitive loading as a precipitating/causative factor in voice disorders. While addressing the short term effects of cognitive loading on the voice, it can broaden our understanding of acute responses of the laryngeal mechanism to mental state of a person. The present study aimed at exploring a more objective and quantifiable method to enumerate the effect of cognitive load on voice and gender variabilities.

**Aim of the study**

The aim of the present study is to investigate effects of cognitive load on vocal parameters in normal young adults.

# CHAPTER II

# REVIEW OF LITERATURE

Cognitive load refers to the amount of mental demand imposed on the cognitive system of a person while he/she is performing a task, and is closely related to the limitations of human working memory resource (Shriberg, Bear, Dowding, 1992; Pass, Tuovinen, Tabbers, Van Gerven, 2003). During any task with high cognitive load, the mental demands exceed the available cognitive capacity leading to deterioration in the performance of the individual. Thereby it disrupts the internal balance of the organism leading to several physiological changes. One such vulnerable system in human body where the changes due to external stimuli can be encountered vividly is the autonomic nervous system (ANS) which is known to be primarily involved in the response to conditions such as cognitive load and involves cardiovascular alterations, neuroendocrine, autonomic reactions, and psycho-neuroimmunologic changes (Iversen, Iversen, and Saper, 2000; Kemeny, 2003). These changes in the body due to ANS are also known to evidently disrupt speech subsystems. Thus with the help of speech based measurements, it would be possible to draw conclusions on the behavior of speech sub-systems and their functions under the high cognitive load condition. Yin and Chen (2007) investigated the effect of cognitive load on speech by inducing an experimental task (traffic management scenarios) with different difficulty levels (cognitive load levels) based on different city maps and time pressure. The speech of the participants were recorded and analyzed for specific speech features. Results indicated speech based features were sensitive enough and reflected the changes in cognitive load in more precise manner. The rate of pauses and rate of pitch peaks were found to have significant increase in values with increase in cognitive load.

**Effect of cognitive load on voice**

Researchers have evidenced that the metabolic changes often influence the voice characteristics in various ways and several vocal symptoms could be associated with the impact of cognitive load. Park and Behlau (2011) stated based on their study that there exists a strong relationship between neuro-vegetative signs and behavioral dysphonia thus indicating that individuals with voice problems have greater lability of the autonomic nervous system. There are many empirical evidences to establish unequivocal support for this premise of relationship between human voice and autonomic nervous system in the literature (Aronson, Peterson, Litin, 1966; Demmink-Geertman, Dejonckere, 2002; Dietrich, Verdolini, Schmith, Rosen, 2006). Consistent with the above findings, Deitrich (2009) speculated activation of the vagus nerve as overcompensation for sympathetic activation. The vagus nerve supplies the intrinsic laryngeal muscles and serves as the primary nerve in the parasympathetic nervous system; therefore, larynx is the most sensitive organ of the human body which reflects number of vocal symptoms when disturbed. Human voice is produced by highly coordinated interaction of respiratory, phonatory, resonatory and nervous system. Any change deviating from normal functioning in these systems will be reflected in individual's voice. Bronchodilation as a result of sympathetic arousal commonly results in increased voice onset time (VOT) and voice production at higher lung volumes (Hoit, Solomon, Hixon, 1993). In agreement with the above explanations, researchers have also reported supra-laryngeal adjustments may also occur under workload conditions. Few studies reported vocal symptoms under cognitive load condition may occur due to lack of synchronization between subglottal air pressure and medial compression of the vocal folds (Tolkmitt, Helfrich, Standke, and Scherer, 1982). The respiratory system and the laryngeal system are probably modified in high cognitive load condition and these would in turn alter the manner of excitation of the vocal apparatus but information regarding to what degree such changes happens and possibly precipitate the vocal symptoms are still under research. It can be inferred from above studies that overtaxing in individual's cognitive system probably results in sympathetic arousal which in turn causes changes in body function making it more vulnerable for voice production (inadequate, unbalanced muscular behavior in larynx and disrupted coordination in speech sub-systems) leading to change in voice characteristics.

Many researches have been carried in an effort to identify specific vocal symptoms in pilots, astronauts, drivers etc. under simulated cognitive load condition which might aid in forestalling in-flight catastrophes. Thus it paved way for development of voice recognition systems in these fields. Kuroda, Fujiwara, Okamura, Utsuki, (1976); Simonov and Frolov, (1977); and Simonov, Frolov, Ivanov, (1980) reported increasing trend in F0 measures with increasing levels of cognitive load during their attempts to document vocal symptoms of male aviators, paratroopers, and air traffic controllers. Spectral tilt has been shown to be less steep (i.e. more gradual fall of the spectrum at higher frequencies) in speech produced under cognitive load (Klatt and Klatt, 1990).

Hecker, Stevens, Bismarck, Williams, (1968) investigated manifestations of cognitive load in acoustic speech signal. They induced cognitive load to 10 participants through arithmetic task under time pressure. The level of load was controlled and deployed by varying the duration of display and available time for the response. Test phrases obtained during the arithmetic task (high load condition) and control task (low load condition) were analyzed and compared. The results indicated that there are a number of conceivable manifestations of cognitive load in the acoustic speech signal. Fundamental frequency differed significantly across the two tasks in all the subjects but both lowering and increasing trends were found. Spectrograms revealed lengthened and irregular glottal period at the end the utterances that was produced under cognitive load. They also observed significant change in the amount of high-frequency energy in the glottal pulses which was more evident in front vowels than in back vowels. Results implied that subjects had less precise control over voicing onset for the utterances produced during cognitive load. In addition, less fluctuations in fundamental frequency was evident in the spectrogram correlating with the perceptual monotonicity in the utterances during high load condition. In some subjects, they also noted voicing irregularity and a tendency to generate certain consonants and vowels more rapidly often with a less constricted vocal tract. Likewise, Brenner, Branscomb, Schwartz, (1979) have reported significant increases in F0 and vocal intensity while analyzing voices of 17 male subjects who were performing a manual tracking task under varying mental workload levels. They also observed a decrease in frequency modulation while performing arithmetic task under time pressure.

Griffin and Williams (1987) evaluated the effect of cognitive load on F0, intensity, and word duration for 20 student naval aviators while performing dichotic listening, plus visual tracking, plus counting task (i.e. maximum workload). Vocal utterances elicited during four levels of task loading with increasing complexity were subjected to acoustic analyses by Visi pitch (model 6087). Results revealed that increasing levels of complexity brought about significant increase in F0, peak amplitude and significant decrease in word duration. By interpreting the results, the experimenters stated that modifications in speech characteristics occur vividly with increasing levels of cognitive load.

Tolkmitt and Scherer (1989) studied effect of emotional stress and cognitive load in speech of both male and female students. Following parameters were extracted from the experimental speech samples, namely: mean F0, F0 floor, formant location, and spectral energy distribution. Subjects were categorized into three groups (low-anxious, high-anxious, or anxiety-denying coping style) based on scores obtained in the Manifest Anxiety Scale (Taylor, 1953) and the Social Desirability Scale (Crowne and Marlow, 1964). Subjects were instructed to solve logical problems with various levels of difficulty. During the task, the five vowels /a/, /i/, /ai/, /o/ and /u/ were displayed on each set of slides and subjects were instructed to read out this code whenever they see it on the screen. They noted in results that *mean* F0 is not as sensitive toward cognitive load as F0 *floor*. In low anxious subjects, F0 floor was observed to slightly decrease in high cognitive load condition whereas, it increased in high-anxious groups. Similar trend was found for the formant distance values in high anxious subjects but this variation was more significant in case of female subjects although it was insignificant for males to which authors speculated that for males, arousal levels induced by the various conditions were too small to have a significant effect on phonatory and articulatory behavior. Whereas in females, authors attributed this increasing trend in the values as denial behavior exhibited by them in order to hide increasing cognitive load. Therefore authors concluded that women experience cognitive load as significantly more difficult, arduous, and arousing than males.

Lively, Pisoni, Van Summers, and Bernack, (1993) explored the acoustic correlates of glottal and supra-laryngeal adjustments, and changes in articulatory timing, as a function of cognitive workload. Five male native speakers of English were recruited as subjects and they were asked to perform a compensatory visual tracking task (cognitive load condition) while producing test utterance- "Say hVd again" which was embedded with several vowels. Acoustic measurements of the utterances produced under cognitive load and control condition (utterances produced without performing the visual tracking task) were compared. Results revealed significantly higher amplitudes in cognitive load condition than the control condition for the entire phrase, as well as for the /h/, hVd vowel, and /d/ closure segment. Other changes outlined in the study were increased amplitude variability, vowels with more high-frequency energy, changes in spectral tilt in high load condition. Regarding F0 parameters, researchers found that only one talker increased F0 during the task for the entire carrier phrase and two talkers showed increased F0 for the vowels in the hVd context. Moreover, three subjects demonstrated a significant drop in F0 variability over the entire phrase while performing the task. Analyses of duration parameters revealed four of the five talkers having reduced overall phrase duration under cognitive load. Similarly even segmental duration was also reduced for some subjects while performing the task. But cognitive workload did not reveal any significant change in the frequencies or bandwidths of the first three formants of the vowels tested. These results of the present study demonstrated a number of acoustic changes in speech which the authors attributed to changes occurring in both laryngeal and sub-laryngeal structures and modifications in the absolute timing of articulatory gestures owing to cognitive demands.

Streeter, Macdonald, Apple, Krauss, Galotti, (1993) analyzed the conversations carried out by two employees on the telephone during the 1977 New York blackout. It revealed that F0 and intensity of one of the employee's voice was higher and no such significant effect in the voice of the other employee.

Mendoza and Carballo (1998) attempted to analyze vocal parameters obtained during cognitive load task. Eighty-two undergraduate students, both males and females, participated in the study. Cognitive load induction methods included four experimental conditions: 1) a baseline measure in which subjects spelled the Spanish alphabet. 2) Reading a tongue twister, 3) Reading a tongue twister with delayed auditory feedback, 4) Spelling the Spanish alphabet in reverse order. In all the conditions, participants were required to prolong the vowel /a/ for approximately 5 seconds after the appearance of red light midway through the task. The recorded samples were analyzed through Multidimensional voice program and parameters such as vocal F0, F0 range, pitch perturbation quotient, amplitude perturbation quotient, noise-to-harmonic ratio (NHR), soft phonation index (SPI) and Voice turbulence index (VTI) were extracted. The multivariate repeated measures analysis with four variables (four conditions) was performed and results indicated a significant increase in F0 and a reduction in jitter as compared to baseline for all the conditions. Shimmer effects were contingent to task with a reduction exhibited only in the tongue twister condition. Frequency and amplitude perturbation measures decreased significantly but there was no difference found in F0 range and STD across the tasks. The spectral energy values (NHR, SPI, and VTI) seemed to be significantly diminished in high load conditions which the authors attributed to greater adduction of the vocal folds during phonation in these conditions.

Johannes, Salnitski, Gunga, Kirsch, (2000) observed two F0 patterns during a spacecraft docking, which is a cognitively loading task. One of the three male pilots showed decreased F0, whereas the remaining two pilots showed increased F0 while docking.

Scherer, Grandjean, Johnstone, Klasmeyer, and Bänziger (2002) reported results of a study conducted on 100 male speakers from three language groups, using a computer-based cognitive load induction procedure that utilized single task condition (simple logical reasoning) and dual task condition (with auditory distractions). During the task, the subjects were instructed to read aloud some standard phrases that appeared on the pop-up windows, which was recorded and acoustically analyzed. Comparison was made between single task condition and dual task condition. The results suggested that cognitive load due to single task condition increased speech rate, the gradient of energy attack and decay gradients, mean F0, and the proportion of energy in the higher frequency range. In contrast, only F0 and the change in spectral energy distribution seemed to respond to the induction of cognitive load through dual task condition. Authors concluded stating that single task condition (logical reasoning) precipitated cognitive and attentional demands which primarily influences fluency and speaking rate in speech whereas dual task condition (with auditory distractions) leads to sympathetic activation and mostly affects F0 parameters.

Rothkrantz, Wiggers, Wees, Vark, (2004) measured acoustic changes in the voice brought about by cognitive workload trial using a modified stroop test. Acoustic analysis revealed changes in F0, vocal jitter, and speaking rate that were dependent upon each study phase. 108 native Dutch speakers performed the experimental task (a variation of Stroop-test with time pressure was used) in which a gradual increase of the level of difficulty was incorporated in 5 phases. The results of the study were enumerated based on these phases which corresponded to increase in cognitive load levels. 1$^{st}$ phase was a baseline measure which was compared with other phases. In 2$^{nd}$ phase, experimenters found increase in the fundamental frequency, a decrease in the duration, jitter and high frequency energy whereas the fundamental frequency variation remained approximately the same. 3$^{rd}$ phase indicated decrease in fundamental frequency compared to the previous condition, but was still slightly higher than the 1$^{st}$ phase. Duration and jitter were stable in this phase and the high frequency energy ratio was low but fundamental frequency variation showed an increase. In 4$^{th}$ phase, the experimenters observed a steep increase in fundamental frequency and F0 variation but a stable jitter ratio, but lowering of high frequency energy. 5$^{th}$ phase (final phase with highest load) revealed a significant decrease in jitter ratio and high fundamental frequency and F0 variation.

Lierde, Van Heule, Ley, Mertens, Claeys, (2009) investigated effect of mental loading tasks on female voice and found that in a cognitive load-inducing and challenging condition the female voice is more breathy, strained and of a lower quality with a lower F0, intensity and aerodynamic capacity. 54 female students with ages ranging from 17.1 to 21.9 years (mean age, 19.3 years) participated in the study. The students were required read a passage before large audience for which seven specific instructions were provided. These instructions evoked cognitive load because students were required to read the passage in a specified manner with perfect speech intelligibility. The non-loading condition consisted of a repetition of the speech before no audience. Both subjective (perceptual evaluation) and objective (aerodynamic, voice range, acoustic measurements, and dysphonia severity index) measurements were carried out to determine voice characteristics of the participants. The speech samples from the two conditions were analyzed and compared. Comparison revealed that F0, MPT, vocal range capacity and the DSI were significantly decreased in the cognitive load-inducing condition. Experimenters also observed significant difference in perceptual findings as subjects' voices in the load-inducing condition were perceptually judged as more breathy, strained and characterized by decreased overall vocal quality in comparison with the relaxed condition. Remarkably this study showed no significant changes (except for the F0) in frequency and amplitude parameters between the two conditions.

Dietrich and Abbott (2012) induced cognitive load through a public speaking task in a group of fifty four female participants. They noted both F0 and vocal intensity measures were significantly reduced in cognitive load condition along with heightened electromyography signals.

Yap, Epps, Ambikairajah, Choi, (2015) investigated how cognitive load affects the voice source characteristics in 26 native English speakers who participated in the study. Both speech and Electroglottography (EGG) signals were recorded simultaneously during performance of four sets of tasks in the following order: (1) Story reading task, (2) Stroop test with time pressure, (3) Reading span task, and (4) Stroop test with dual task. In each task cognitive load levels corresponded to low, medium and high with increase in task complexity. EGG measures, glottal flow measures and speech spectrum based glottal measures were extracted during the analyses. Results showed that the minima of the EGG signal seemed to be sharper and less rounded as a function of increase in cognitive load which implied that the vocal folds remain open for a shorter duration of time at high load condition. The first-order Derivative of EGG (DEGG) showed a clearer trend wherein the peaks of DEGG waveforms tended to become more prominent: positive peaks became more positive and negative peaks became more negative with increased cognitive load. Authors inferred that the rate at which the vocal folds are opening and closing increased as a function of cognitive load. With the EGG waveforms, authors made observations that under low load conditions, vocal folds open and close in a zip-like fashion, whereas under high load conditions, vocal folds open and close in an abrupt manner. The glottal flow waveform obtained under high cognitive load, seemed to have a larger closed phase and a smaller open phase: the glottal pulses were narrower. Authors also noted the changes in the glottal flow waveform tended towards the direction of the characteristics of a creaky voice quality i.e. vocal fold vibration was irregular and the vocal folds are compressed tightly. While measuring speech spectrum based glottal parameters, harmonics to noise ratio (HNR) did not show any reliable trends with increase in cognitive load. On the other hand, the mean values of H1 – H2 (corrected difference of first two harmonic amplitudes) exhibited a monotonically decreasing trend with increase in cognitive load to which authors stated that speech has a less breathy characteristic. Similarly cepstral peak prominence (CPP) means showed an increasing trend as cognitive load increased from low to medium load, which again suggested a less breathy voice quality. Therefore authors concluded that speech tends to exhibit a less breathy characteristic as cognitive load increases.

Su and Luz (2015) investigated acoustic parameters analyzed from recorded speech samples of 20 males and 6 females who were subjected to perform four types of different experimental tasks: reading span sentence, reading span letter, stroop time pressure and stroop dual task. These tasks consisted three distinct cognitive load levels classified based on complexity of the task - low (L1), medium (L2) and high (L3) levels. Experimenters found that frequency signals (MFCC and F0) and sound quality measures (log HNR) showed significant changes with respect to the levels of cognitive load, whereas energy related features (root mean square) seemed contingent to the tasks.

In Indian context, a few studies have been attempted by inducing cognitive stress. Ruhi Agarwal (1999) utilized a list of 10 tongue twisters and 15 English words as stimuli to induce cognitive load at different load levels by incorporating experimental tasks such as reading under delayed auditory feedback (DAF) and reading in reverse order. The utterances were recorded which were then analyzed through Multi-dimensional voice program (MDVP) and 29 acoustic parameters were extracted. Lowering of highest F0, Jita values, relative average perturbation (RAP), soft phonation index (SPI), pitch perturbation quotient (PPQ) and shimmer percent were observed in high load experimental conditions. Standard deviation of fundamental frequency (STD) values and smoothened pitch perturbation quotient (sPPQ) were observed to lower only in case of females whereas in it did not show any significant trend in males. Author also noted a slight increase in Jitter percent and frequency tremor intensity index (FTRI) compared to norms. Greater amplitude variability was seen in high load tasks which was more significant for females than males. Higher voice turbulence index (VTI), degree of sub-harmonic breaks (DSH), Number of sub-harmonic breaks (NSH) and degree of voiceless units (DUV) were observed in high load tasks for both males and females. Other measures did not show any significant differences with respect to control and experimental conditions.

Cognitive load may cause a series of physiological and psychological changes when individual is confronted with cognitive demands exceeding the available capacity of human cognitive system. Whether this resultant physiologic change is person specific or not is still debated. Literature evidences in this line suggest that individuals adapt to confronted cognitive load and react in idiosyncratic ways. The manner in which each individual adapts and responds to different levels of cognitive load has a great deal of individual variability and warrants further investigation.

Review of literature indicates that speech based measurements were used extensively to quantify cognitive load but the tasks used were several, ranging from dual tasks, time-bound reading tasks, reading tasks with specific instructions for clear diction/pronunciation, stroop tasks, tongue twisters, reverse spelling, arithmetic tasks, reasoning tasks etc. In addition, from the above findings, it can be determined that the effect of stroop is superior in inducing cognitive load. Voice measurements, being more objective can reveal more precise information regarding the extent of cognitive load and consequential degree of variations that maybe present in the physical features of an individual's voice.

In this regard, the present study was planned with the following specific objectives:

- To investigate the effects of cognitive loading on vocal acoustic parameters
- To check and compare the extent of changes in vocal acoustic parameters according to graded complexities of cognitive loading (level 1 and level 2)
- To determine gender variabilities in vocal parameters in response to cognitive loading.

# CHAPTER III

# METHOD

## Subjects

Fifty subjects (25 males and 25 females) ranging in age from 18 to 22 years with the mean age of 18.22 years (Standard Deviation: 0.76) were recruited to participate in this study. All subjects reported normal hearing sensitivity and normal eye sight or corrected to normal sight and they were excluded if they had any history of Speech and language impairment, neurological or psychological problems and complaint of any infections related to ear, nose and throat at the time of testing. In addition, subjects who reported to have undergone professional training in singing were also excluded from the study. All participants were naive to the purpose and procedure of the experiment and consented for participation in the study.

## Stimuli: Stroop test with pressure

The Stroop test (Stroop, 1935) is a well-known test to assess the cognitive functions and has now been in existence for 80 years. The native form of stroop test measures stroop effect i.e., color-word interference which relies mainly on the strong overlearned tendency of the experienced readers for whom the reading of a word has become an automatism and they pay attention to the meaning of the stimulus rather than the superficial feature (colour/font) of the stimulus. In the current study a variation of stroop test incorporated with time pressure was used in order to induce cognitive loading. This test consisted of two levels with increasing complexity fed with both congruent and incongruent stimuli.

Congruent stimulus:

| Stimulus | Target response |
|---|---|
| RED | “Red” |

Incongruent stimulus:

| Stimulus | Target response |
|---|---|
| RED | “Blue” |

a. Level 1 (Low cognitive load condition): Both congruent and incongruent stimuli in SET 1 were randomly presented with the time limit of 2 seconds with no distractions i.e. each stimulus color appeared only for 2 seconds in the “center” of the laptop screen

b. Level 2 (High cognitive load condition): It consisted of 3 sets within the level – SET 2, SET 3 and SET 4. Only incongruent stimuli were presented with the time limit of 1.5 seconds in SET 2, 1 second in SET 3 and 0.5 seconds in SET 4. Distractions were incorporated (stimuli appeared randomly in any part of the laptop screen) in this level along with gradually increasing time pressure to induce high cognitive load.

*Table 1*: *Set of colours used as stimuli in the study*

| STIMULI | |
|---|---|
| BLACK | WHITE |
| YELLOW | GREY |
| BLUE | PINK |
| RED | GREEN |
| BROWN | ORANGE |

*Table 2*: *Task and stimuli with respect to baseline and complexity levels*

| | | | | | | |
|---|---|---|---|---|---|---|
| Baseline (phonation sample 1) | LEVEL 1 (Low cognitive load) Both congruent and incongruent stimuli were randomly presented with the time limit with no distractions. | | LEVEL 2 (High cognitive load) Only incongruent stimuli were randomly presented with the time limit with distractions incorporated. | | | |
| | SET 1 (2 secs) Naming | Beep sound phonation sample 2 | SET 2 (1.5 secs) Naming | SET 3 (1 sec) Naming | SET 4 (0.5 secs) Naming | Beep sound Phonation sample 3 |

**Task**

1) ***Naming task***: During the test, the participants were required to name the Font color of each stimulus accurately within the time limit.
2) ***Phonation task***: Phonation task was carried three times as explained below:
   a) Baseline measurement: Sample 1 – phonation of vowel /a/ for about 5 seconds prior to the beginning of the test
   b) Sample 2 – phonation of vowel /a/ for about 5 seconds following the buzzer indicator.
   c) Sample 3 – phonation of vowel /a/ for about 5 seconds following the buzzer indicator.

   *The buzzer signal was an alert signal for the subject to initiate phonation task.

## Instructions

All the participants were instructed individually about the stroop experiment and the phonation tasks corresponding to three conditions. Participants were seated comfortably and maintained appropriate distance from the microphone placed in front of them.

*Instructions for stroop test*: “There are two levels in this test: level 1 and level 2. In each level several set of words (colours) will appear one after the other on the computer screen for relatively short period of time. You will have to concentrate and name the Font colour of the word accurately. Your correct responses will be documented”.

*Instructions for phonation task*: “You will be required to phonate the vowel /a/ for about 5 seconds before the test procedure starts and similarly during the test, after completion of the Set 1 and after completion of Set 4. There will be a buzzer signal to indicate that you are required to begin phonating the vowel /a/ for about 5-6 seconds. Your voice samples and responses will be recorded simultaneously”.

## Instrumentation

*Stroop task* – the stroop test protocol was custom designed in JavaScript of HTML under the technical guidance of concerned professional and was run through Dell INSPIRON laptop.

*Recording and analysis* - phonation samples were recorded in CSL model 4500 of version 3.1.7 by Kay PENTAX and analyzed using Multidimensional Voice Profile model 5105 of CSL 4500 by Kay PENTAX.

**Recording**

The phonation samples were directly recorded with a microphone, onto the module of CSL model 4500 of version 3.1.7 by Kay PENTAXof using 22k Hz sampling rate in a quiet environment controlled for the testing procedure. The recorded data was saved and analysed using Multidimensional Voice Profile model 5105 of CSL 4500 by Kay PENTAX for extraction of the vocal parameters.

**Procedure**

Each subject was instructed and tested individually in a quiet environment in the Laboratory of department in the institute. The subject was seated comfortably facing a laptop screen displaying stroop stimuli and the microphone placed at a fixed distance of 4' to 5' inches away from subject's mouth. Baseline phonation task was carried out in the beginning, prior to the presentation of stroop test. During the stroop test, subjects uttered the font colour of the word that appeared on the laptop screen for relatively short period of time as given in level 1 and level 2 and phonated vowel /a/ after the buzzer indicator. The phonation samples were recorded as baseline, sample 1 (during Level 1 of stroop test) and sample 2 (during level 2 of the Stroop test) and they were analysed.

**Analysis**

The vocal parameters under these following major categories were extracted:

I. Fundamental frequency information measures

   1. Average fundamental frequency (F0) – average value of all extracted period to period fundamental frequency values in a voice signal.

2. Average pitch period (T0) – the average value of all extracted pitch period values.
3. Highest fundamental frequency (Fhi) – the greatest of all extracted period to period F0 values in a voice signal.
4. Lowest fundamental frequency (Flo) – the lowest of all extracted period to period F0 values in a voice signal.
5. Standard deviation of fundamental frequency (STD) – standard deviation of all extracted period to period F0 values in a voice signal.

II. Short and long term frequency perturbation measures

1. Absolute jitter (Jita) – the period to period variability of the pitch period in a voice signal.
2. Jitter percentage (Jitt) – relative evaluation of the period to period variability of the pitch in a voice signal
3. Relative average perturbation (RAP) – relative evaluation of the period to period variability of the pitch in a voice signal with a smoothing factor of 3 periods.
4. Pitch perturbation quotient (PPQ) - relative evaluation of the period to period variability of the pitch in a voice signal with a smoothing factor of 5 periods.
5. Smoothened pitch perturbation quotient (sPPQ) – relative evaluation of the short or long term variability of the pitch period in a voice signal at smoothing factor defined by the user.

6. Fundamental frequency variation (vF0) – variation of F0 in a voice signal; relative standard deviation of period to period calculated F0.

III. Short and long term amplitude perturbation measures

1. Shimmer in dB (ShdB) – the period to period variability of the peak to peak amplitude measured in dB of a voice signal
2. Shimmer percentage (Shim) – relative evaluation of the period to period variability of the peak to peak amplitude in a voice signal
3. Amplitude perturbation quotient (APQ) – relative evaluation of the period to period variability of the peak to peak amplitude of the voice signal.
4. Smoothened amplitude perturbation quotient (sAPQ) – relative evaluation of the short or long term variability of the peak to peak amplitude in a voice signal at smoothing factor defined by user.
5. Peak amplitude variation (vAm) – relative standard deviation of the peak to peak amplitude; reflects peak to peak amplitude variation in a voice signal.

IV. Noise related measures

1. Noise to harmonic ratio (NHR) – average ration of the inharmonic spectral energy in the frequency range 1500-4500 Hz to the harmonic spectral energy in the frequency range 70-4500 Hz.
2. Voice turbulence index (VTI) – average ratio of the spectral inharmonic high frequency energy in the range 2800-5800 Hz to the spectral harmonic energy in the range 70-4500 Hz in areas of the signal where the influence of frequency and amplitude variations, voice breaks and subharmonic components are minimal.

3. Soft phonation index (SPI) – average ratio of the lower frequency harmonic energy in the range 70-1600 Hz to the higher frequency harmonic energy in the range 1600-4500 Hz.

V. Tremor related measures

1. F0 tremor frequency (Fftr) – the frequency of the most intensive low frequency F0-modulating component in the specified F0 tremor analysis range.
2. Amplitude tremor frequency (Fatr) – the frequency of most intensive low frequency amplitude modulating component in the specified amplitude tremor analysis range.

3. F0 tremor intensity index (FTRI) – average ratio of the frequency magnitude of the most intensive low-frequency modulating component (F0 tremor) to the total frequency magnitude of the analysed voice signal.
4. Amplitude tremor intensity index (ATRI) – average ratio of the amplitude of the most intense low frequency amplitude modulating component (amplitude tremor) to the total amplitude of the analysed voice signal.

**Statistical analysis**

The data was subjected to statistical analysis using SPSS software version 20. Descriptive measures, Mixed ANOVA (Parametric test -for parameters which were normally distributed), Mann-Whitney U test, Friedman's test and Wilcoxon Signed-rank test (Non parametric tests -for parameters which were not normally distributed) were performed to check level of significance across complexity levels and between genders.

# CHAPTER IV

# RESULTS AND DISCUSSION

A total of fifty subjects (25 females and 25 males) participated in the study. The test utilized to induce cognitive load in the subjects of the present study was a variation of Stroop test with time pressure which consisted of two levels with increasing complexity. Phonation samples obtained during each complexity level and the baseline were analyzed using Multi-dimensional Voice Profile (MDVP) model 5105 of CSL-4500 by Kay PENTAX and vocal parameters were extracted. Analyzed data were subjected to statistical analysis. Twenty three MDVP parameters were considered for statistical analysis for which means and standard deviation were obtained. Among them, only four parameters were normally distributed and Mixed ANOVA (Repeated measure ANOVA across complexity levels with gender as a between factor) was performed to find the significance. Other parameters were analyzed with non-parametric tests - Mann-Whitney U test, Friedman's test and Wilcoxon Signed-rank test. The results obtained for these 23 vocal parameters will be discussed under following major categories:

I. Fundamental frequency information measures
II. Short and long term frequency perturbation measures
III. Short and long term amplitude perturbation measures
IV. Noise related measures
V. Tremor related measures

## I. Fundamental frequency information measures

*Table 3: Means and standard deviation of Fundamental frequency information measures across complexity levels in both males and females*

| Parameters | Females | | Males | |
|---|---|---|---|---|
| | **Mean** | **SD** | **Mean** | **SD** |
| **F0_B** | 238.73 | 21.64 | 137.62 | 18.53 |
| **F0_1** | 234.38 | 19.32 | 135.27 | 20.89 |
| **F0_2** | 234.39 | 19.86 | 135.67 | 19.77 |
| **T0_B** | 4.22 | .36 | 7.39 | .99 |
| **T0_1** | 4.29 | .34 | 7.56 | 1.14 |
| **T0_2** | 4.29 | .35 | 7.52 | 1.11 |
| **Fhi_B** | 250.34 | 23.75 | 141.91 | 20.05 |
| **Fhi_1** | 246.73 | 21.29 | 138.92 | 21.94 |
| **Fhi_2** | 244.38 | 20.89 | 138.44 | 20.26 |
| **Flo_B** | 226.95 | 23.33 | 133.53 | 17.85 |
| **Flo_1** | 223.49 | 19.39 | 131.75 | 20.23 |
| **Flo_2** | 225.51 | 20.23 | 132.71 | 19.34 |
| **STD_B** | 3.12 | 1.41 | 1.37 | .65 |
| **STD_1** | 3.51 | 1.59 | 1.25 | .66 |
| **STD_2** | 3.00 | 1.38 | 1.10 | .33 |

*(_B) baseline, (_1) level 1, (_2) level 2

The mean and standard deviation values of fundamental frequency information measures obtained in each level for both genders are presented in table 3. The mean values of F0 were observed to be slightly increased (M in females= 238.7, M in males= 137.6) in baseline relative to other two complexity levels in both males and females (M in females= 234.3, M in males= 135.3). The similar trend was seen in Fhi and Flo. However, other variables did not show any major observable differences in the mean values across the complexity levels for both genders.

*Table 4: F and significance values of fundamental frequency information measures in males and females across complexity levels*

| Parameters | | F | Sig. |
|---|---|---|---|
| **F0** | Level | 4.158 | .019* |
| | Gender | 332.757 | .000* |
| | Level*Gender | .484 | .618 |
| **T0** | Level | 5.679 | .005* |
| | Gender | 206.764 | .000* |
| | Level*Gender | .753 | .474 |
| **Fhi** | Level | 4.145 | .019* |
| | Gender | 350.713 | .000* |
| | Level*Gender | .298 | .743 |
| **Flo** | Level | 1.482 | .232 |
| | Gender | 292.730 | .000* |
| | Level*Gender | .153 | .858 |

* Significance level <0.05; (_B) baseline, (_1) level 1, (_2) level 2

Table 4 depicts Mixed ANOVA results of fundamental frequency information measures across three complexity levels (baseline, level 1 and level 2) with gender as between factor. Results revealed significant main effect of levels in the variables F0 {$F_{(2, 96)} = 4.158$; $p<0.05$}, T0 {$F_{(2, 96)} = 5.679$; $p<0.05$}, Fhi {$F_{(2, 96)} = 4.145$; $p<0.05$} whereas Flo did not. Furthermore, all these variables also showed overall significant differences between males and females but no interaction effect between level and gender.

*Table 5: |z|, $\chi^2$ and significance values of standard deviation of fundamental frequency (STD)*

| Parameters | | \|z\| | Sig. | $\chi^2$ | | Sig. |
|---|---|---|---|---|---|---|
| STD | L_B | 4.647 | .000* | Females | 5.360 | .069 |
| | L_1 | 5.016 | .000* | | | |
| | L_2 | 5.287 | .000* | Males | 1.520 | .468 |

* Significance level <0.05; (_B) baseline, (_1) level 1, (_2) level 2

Table 5 indicates the results of Mann Whitney U test used to compare between genders and Friedman's test to compare across complexity levels. Comparison between males and females using Mann Whitney U test across all three levels showed significant differences. On the other hand, results of Friedman's test did not show any significant effect across complexity levels in both males ($\chi^2$= 5.360, p = 0.468) and females ($\chi^2$= 1.520, p = 0.069). From the above findings, we can infer that standard deviation of fundamental frequency (STD) did not show any significant change across complexity levels in both males and females unlike other fundamental frequency measures which is in agreement with study by Mendoza and Carballo (1998) who found no difference in STD across tasks. It is probably due to phonation sample used whose F0 should supposedly stay constant in the absence of vocal pathology.

The results of the present study indicated that most fundamental frequency information measures showed significant differences across complexity levels and assumed a decreasing trend with increase in cognitive load level. The control of F0 is an intricate interaction between respiratory system (i.e., subglottic pressure) and laryngeal system (i.e., intrinsic laryngeal muscle activation affecting vocal fold posture). In this study it may be speculated that sudden cognitive demands imposed on the human brain interfered with normal vocal fold physiology resulting in series of changes such as mucous retention, incomplete drainage, drying of cover, increased mass and thus decreased subglottal pressure leading to decrease in fundamental frequency. Absence of interaction effect revealed that both males and females follow a similar trend when they encounter high cognitive load. This finding is in agreement with Lierde, et al., (2009) and Dietrich and Abbott (2012) who found significant reduction in F0 during high cognitive load conditions. On the contrary, several studies have also reported significant increase in F0 measures or inconsistent change in F0 in the subjects, when they are subjected to high cognitive load conditions (Brenner et al., 1979; Griffin, Williams, 1987; Mendoza, Carballo, 1998; Rothkrantz et al., 2004). In a similar study done by Ruhi Agarwal (1999), the results showed no significant changes in other fundamental frequency information measures except Fhi which showed a lowering trend in high cognitive load condition. The significant differences observed in fundamental frequency information measures in the present study is in support with the view that high cognitive load conditions induces changes in laryngeal and sub-laryngeal structures (Lively et al., 1993).

In addition to above findings, it was also noted that there is a significant overall difference in fundamental frequency information measures in males and females which can be attributed to anatomic and physiologic differences of vocal apparatus between genders (Titze, 1989).

## II. Short and long term frequency perturbation measures

*Table 6: Means and standard deviation of short and long term frequency perturbation measures across complexity levels in both males and females*

| Parameters | Females | | Males | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| **Jita_B** | 59.06 | 36.02 | 61.43 | 38.22 |
| **Jita_1** | 74.73 | 43.64 | 69.16 | 40.97 |
| **Jita_2** | 63.36 | 38.02 | 48.06 | 24.43 |
| **Jitt_B** | 1.38 | .78 | 1.00 | .52 |
| **Jitt_1** | 1.71 | .96 | .91 | .62 |
| **Jitt_2** | 1.46 | .84 | .64 | .32 |
| **RAP_B** | .83 | .47 | .62 | .37 |
| **RAP_1** | 1.04 | .58 | .66 | .42 |
| **RAP_2** | .88 | .50 | .41 | .18 |
| **PPQ_B** | .82 | .47 | .53 | .28 |
| **PPQ_1** | .99 | .56 | .61 | .36 |
| **PPQ_2** | .84 | .48 | .38 | .19 |
| **sPPQ_B** | .85 | .42 | .64 | .27 |
| **sPPQ_1** | 1.03 | .51 | .67 | .32 |
| **sPPQ_2** | .88 | .45 | .54 | .19 |
| **vF0_B** | 1.32 | .63 | 1.02 | .37 |
| **vF0_1** | 1.50 | .69 | .95 | .42 |
| **vF0_2** | 1.28 | .59 | .82 | .23 |

*(_B) baseline, (_1) level 1, (_2) level 2

Table 6 shows the means and standard deviation of short and long term frequency perturbation measures across three different complexity levels in both males and females. The above table demonstrates an unusual trend across complexity levels in all the parameters i.e. there is an increase in frequency perturbation measures in level 1 compared to baseline and a decreasing trend is observed from level 1 to level 2. Although this trend is invariably observed in females for all the parameters, males did not follow the same trend in few parameters such as vF0 and Jitt. Besides, in these parameters there is a steady increase in frequency perturbation values from baseline to level 2 indicating the differences exhibited in direction of changes occurring between genders.

*Table 7: |z|, $\chi^2$ and significance values of Short and long term frequency perturbation measures*

| Parameters | | \|z\| | Sig. | $\chi^2$ | | Sig. |
|---|---|---|---|---|---|---|
| Jita | L_B | .262 | .793 | Females | 7.280 | .026* |
| | L_1 | .301 | .764 | | | |
| | L_2 | .387 | .165 | Males | 9.879 | .007* |
| Jitt | L_B | 1.688 | .091 | Females | 7.280 | .026* |
| | L_1 | 3.153 | .002* | | | |
| | L_2 | 3.677 | .000* | Males | 3.920 | .141 |
| RAP | L_B | 1.504 | .133 | Females | 7.280 | .026* |
| | L_1 | 2.425 | .015* | | | |
| | L_2 | 3.522 | .000* | Males | 9.918 | .007* |
| PPQ | L_B | 2.241 | .025* | Females | 3.440 | .179 |
| | L_1 | 2.435 | .015* | | | |
| | L_2 | 3.658 | .000* | Males | 12.869 | .002* |
| sPPQ | L_B | 1.795 | .073 | Females | 10.323 | .006* |
| | L_1 | 2.493 | .013* | | | |
| | L_2 | 2.532 | .011* | Males | 2.160 | .340 |
| vF0 | L_B | 1.737 | .082 | Females | 5.515 | .063 |
| | L_1 | 2.833 | .005* | | | |
| | L_2 | 2.571 | .010* | Males | 1.520 | .468 |

* Significance level <0.05; (_B) baseline, (_1) level 1, (_2) level 2

Table 7 reports the results of Mann Whitney U test revealing significant changes observed in variables between genders in each level. The variables, Jitt, RAP, sPPQ and vF0 displayed significant changes only in level 1 and level 2 but in case of PPQ measures, all three complexity levels exhibited significant changes between genders. Interestingly, Jita value has not shown any significant change between males and females at any level.

Friedman's test presents statistically significant changes across complexity levels in both males and females in Jita and RAP measures. However, this significant effect of levels has been found only in females in case of Jitt and sPPQ measures and only in males in case of PPQ measure. Despite the fact that means of vF0 measure shows increasing trend in high cognitive load condition, it fails to present statistical significance.

To precisely examine effect across each complexity level, pairwise comparison was performed with Wilcoxon Signed-rank test. For Jita measures, a significant increase was found between baseline and level 1 ($|Z| = 2.462$, $p = 0.14$) in females whereas in males the change was found to be in decreasing direction between level 1 and level 2 ($|Z| = 3.057$, $p = 0.002$). As expected, Jitt, RAP and sPPQ measures showed statistically significant increase from baseline to level 1 in females ($|Z| = 2.543$, $p = 0.011$; $|Z| = 2.516$, $p = 0.012$; $|Z| = 2.314$, $p = 0.021$). Similarly, males showed a significant decrease in RAP and PPQ measures from level 1 to level 2 ($|Z| = 3.559$, $p = 0.00$; $|Z| = 3.514$, $p = 0.00$).

From the above findings, it may be assumed that males and females respond to cognitive load differently which is in agreement with Tolkmitt and Scherer (1989) who speculated that arousal levels in males and females vary to some extent when subjected to cognitive load and thus each of them experience cognitive load significantly different with unique physiological modifications occurring at laryngeal level. In the present study, both decreasing and increasing trends in frequency perturbation measures resultant of disturbances in periodicity of the vocal fold vibration have been found and this direction of change was contingent to complexity levels and also gender. Females constantly exhibited significant increase of frequency perturbation measures in level 1 (low load condition) and on the other hand, males exhibited significant decrease of frequency perturbation measures in level 2 (high load condition). This interaction also paves way for us to infer that females experienced more cognitive taxing in level 1 (low load condition) during initial phases and probably acclimatized in later phases in level 2 that might have led to suitable accommodation of cognitive resources to cope with task demands and in turn no/less effect on their voice. For males, however the arousal level induced by level 1 (low load condition) was too small to bring about any change and level 2 (high load condition) was experienced as more cognitively loading without adaptation effect. These findings are in parallel with the results of Lively, et al., (1993) who reported significant drop in frequency perturbation measures in high cognitive load conditions only for male participants. On the contrary, Mendoza and Carballo (1998) found significant decrease in frequency perturbation measures in both males and females. A significant decrease in Jita, RAP and PPQ measures was reported by Ruhi Agarwal (1999) who also found inexplicable significant decrease in sPPQ only in females which is in contrast to our current findings. Interestingly, the pattern of changes found in frequency perturbation measures across complexity levels in the present study is to an extent similar to results obtained through a Stroop task by Rothkrantz, et al., (2004) wherein the direction of change in vocal parameters were dependent on the phase of the study. This study witnessed significant increase in acoustic parameters initially and then decreasing trend in later phases.

### III. Short and long term amplitude perturbation measures

*Table 8: Means and standard deviation of short and long term amplitude perturbation measures across complexity levels in both males and females*

| **Parameters** | **Females** | | **Males** | |
|---|---|---|---|---|
| | **Mean** | **SD** | **Mean** | **SD** |
| **ShdB_B** | .30 | .12 | .22 | .05 |
| **ShdB_1** | .29 | .11 | .27 | .10 |
| **ShdB_2** | .26 | .10 | .24 | .10 |
| **Shim_B** | 3.44 | 1.33 | 2.62 | .56 |
| **Shim_1** | 3.35 | 1.23 | 3.21 | 1.23 |
| **Shim_2** | 2.99 | 1.19 | 2.70 | .96 |
| **APQ_B** | 2.48 | .98 | 1.97 | .41 |
| **APQ_1** | 2.30 | .79 | 2.36 | .80 |
| **APQ_2** | 2.07 | .79 | 2.05 | .52 |
| **sAPQ_B** | 3.50 | 1.05 | 3.35 | .72 |
| **sAPQ_1** | 3.46 | 1.36 | 3.69 | .93 |
| **sAPQ_2** | 2.91 | 1.01 | 3.53 | 1.06 |
| **vAm_B** | 6.57 | 2.15 | 5.81 | 1.62 |
| **vAm_1** | 6.85 | 2.63 | 6.23 | 2.30 |
| **vAm_2** | 5.99 | 1.85 | 6.35 | 1.96 |

*(_B) baseline, (_1) level 1, (_2) level 2

The means and standard deviation of amplitude perturbation measures across different complexity levels in males and females are shown in Table 7. On observation, males seemed to follow an atypical trend of increase in mean scores in level 1 (low load condition) and decrease in level 2 (high load condition). Whereas, females showed a steady decrease in amplitude perturbation measures with increasing cognitive load level.

*Table 9: |z|, $\chi^2$ and significance values of Short and long term amplitude perturbation measures*

| Parameters | | \|z\| | Sig. | $\chi^2$ | | Sig. |
|---|---|---|---|---|---|---|
| ShdB | L_B | 1.960 | .050 | Females | 2.240 | .326 |
| | L_1 | .709 | .479 | | | |
| | L_2 | .767 | .443 | Males | 4.560 | .102 |
| Shim | L_B | 2.012 | .054 | Females | 2.240 | .326 |
| | L_1 | .660 | .509 | | | |
| | L_2 | .834 | .404 | Males | 5.120 | .077 |
| APQ | L_B | 1.581 | .114 | Females | 1.680 | .432 |
| | L_1 | .146 | .884 | | | |
| | L_2 | .204 | .839 | Males | 2.480 | .289 |
| sAPQ | L_B | .475 | .635 | Females | 3.120 | .210 |
| | L_1 | 1.649 | .099 | | | |
| | L_2 | 2.183 | .029* | Males | .720 | .689 |
| vAm | L_B | 1.116 | .265 | Females | 2.880 | .237 |
| | L_1 | .960 | .337 | | | |
| | L_2 | .417 | .677 | Males | .560 | .756 |

* Significance level <0.05; (_B) baseline, (_1) level 1, (_2) level 2

The results of Mann Whitney U test and Friedman's test are depicted in table 8. Comparison between males and females carried out using Mann Whitney U test revealed no significant differences except for sAPQ measures in level 2 ($|Z|= 2.183$, $p= 0.29$). Friedman's test also showed no statistical significant changes occurring across complexity levels in both the genders when subjected to cognitive load. Although mean scores showed a uniform trend, it has failed to portray any statistically significant changes.

Lierde, et al., (2009) and Ruhi Agarwal (1999) reported findings parallel to the present study wherein no significant changes were observed in amplitude perturbation measures between high load and low load conditions. Nevertheless, the present study contradicts the results obtained by Mendoza and Carballo (1998) who found significant reduction of Shim only in tongue twister task and other amplitude perturbation measures showed significant decrease in all other tasks with increasing cognitive load level.

*Table 10: Means and standard deviation of Noise related measures across complexity levels in both males and females*

| **Parameters** | **Females** | | **Males** | |
|---|---|---|---|---|
| | **Mean** | **SD** | **Mean** | **SD** |
| **NHR_B** | .12 | .01 | .12 | .02 |
| **NHR_1** | .11 | .02 | .13 | .02 |
| **NHR_2** | .11 | .02 | .13 | .016 |
| **VTI_B** | .05 | .01 | .04 | .013 |
| **VTI_1** | .04 | .01 | .04 | .013 |
| **VTI_2** | .03 | .01 | .03 | .01 |
| **SPI_B** | 11.19 | 4.00 | 17.53 | 7.35 |
| **SPI_1** | 14.68 | 6.07 | 19.11 | 7.79 |
| **SPI_2** | 16.45 | 8.11 | 16.30 | 6.70 |

*(_B) baseline, (_1) level 1, (_2) level 2

The table 10 shows mean and standard deviation values of noise related measures in both males and females across three different levels corresponding to different cognitive load levels. The variables, NHR and VTI did not display any noticeable differences across three levels. However, in case of SPI measure, considerable increase was observed in females with increase in complexity of the level and males exhibited increase in level 1 (low cognitive load) and decrease in level 2 (high cognitive load) similar to frequency and amplitude perturbation measures.

*Table 11: |z|, $\chi^2$ and significance values of noise related measures*

| Parameters | | \|z\| | Sig. | $\chi^2$ | | Sig. |
|---|---|---|---|---|---|---|
| NHR | L_B | .524 | .600 | Females | .990 | .610 |
| | L_1 | 2.902 | .004* | | | |
| | L_2 | 3.746 | .000* | Males | 3.920 | .141 |
| VTI | L_B | 2.825 | .005* | Females | 8.928 | .012* |
| | L_1 | .019 | .985 | | | |
| | L_2 | .573 | .567 | Males | 1.551 | .460 |
| SPI | L_B | 3.192 | .001* | Females | 10.640 | .005* |
| | L_1 | 2.066 | .039* | | | |
| | L_2 | .107 | .915 | Males | 12.480 | .002* |

* Significance level <0.05; (_B) baseline, (_1) level 1, (_2) level 2

Results of Mann Whitney U test and Friedman's test of noise related measures is presented in table 10. Comparison between genders revealed significant differences of NHR measure in level 1 and level 2 (|Z|= 2.902, p= 0.004; |Z|= 3.746, p = 0.00), VTI measure in baseline only (|Z|= 2.825, p= 0.005), SPI measure in baseline and level 1 (|Z|= 3.192, p= 0.001; |Z|= 2.066, p= 0.39).

Changes across complexity levels was found to be significant for both males ($\chi^2$ = 12.480, p= 0.002) and females ($\chi^2$ =10.640, p= 0.005) in SPI and only for females ($\chi^2$ =8.928, p=0.012) in VTI. However, NHR measure did not show any statistically significant change between levels.

Pairwise comparison between each level was further examined by Wilcoxon Signed-rank test. Results revealed significant differences in VTI measure between baseline and level 1 (|Z|= 2.921, p= 0.003) and baseline and level 2 (|Z|= 3.501, p= 0.00) but no significant difference between level 1 and level 2 for females (|Z|= 0.773, p= 0.440). This difference was exhibited in decreasing trend. The similar effect was again found in females for SPI measure also, except for changes were exhibited in increasing trend unlike in VTI. However, males showed significant lowering trend only between level 1 and level 2 (|Z|= 2.892, p= 0.004).

Furthermore, it may be speculated from the above findings that in case of females, the cognitive load has an equivalent effect on voice parameters irrespective of the amount of complexities (high load and low load). The results of the present study did not show same effect on all noise related measures (NHR, SPI and VTI) and it was dependent on levels and even gender. The significant main effect of complexity levels found on VTI and SPI can be related to the fact that incomplete vocal fold adduction occurred as a result of induced cognitive load. This may a result of lack of coordination between subglottal pressure and medial compression of vocal folds as a consequence of encountering high cognitive load. Similar to the above findings, Su and Luz (2015) reported that noise related measures were contingent to the tasks and they utilized several experimental tasks (reading span Sentence, reading span Letter) with three distinct cognitive load levels (L1, L2 and L3). Likewise, Ruhi Agarwal (1999) found significant increase only in VTI measure under cognitive load condition. However, some studies also report contradictory findings in the literature. Mendoza and Carballo (1998) reported significantly diminished spectral energy values (NHR, SPI and VTI) in high cognitive load conditions and conversely, Scherer, et al., (2002) reported significant increase for the same.

*Table 12: Means and standard deviation of tremor related measures across complexity levels in both males and females*

| **Parameters** | **Females** | | **Males** | |
|---|---|---|---|---|
| | **Mean** | **SD** | **Mean** | **SD** |
| **Fftr_B** | 3.56 | 1.72 | 3.64 | 1.35 |
| **Fftr_1** | 5.46 | 3.13 | 4.40 | 2.54 |
| **Fftr_2** | 3.46 | 1.07 | 5.61 | 2.76 |
| **Fatr_B** | 3.86 | 1.49 | 5.19 | 2.32 |
| **Fatr_1** | 3.90 | 1.87 | 4.89 | 2.21 |
| **Fatr_2** | 5.34 | 2.82 | 5.22 | 2.00 |
| **FTRI_B** | .28 | .10 | .27 | .15 |
| **FTRI_1** | .33 | .21 | .26 | .10 |
| **FTRI_2** | .28 | .15 | .31 | .14 |
| **ATRI_B** | 2.31 | 1.75 | 2.55 | 1.38 |
| **ATRI_1** | 2.07 | 1.34 | 2.63 | 1.13 |
| **ATRI_2** | 3.13 | 1.74 | 3.17 | 1.71 |

*(_B) baseline, (_1) level 1, (_2) level 2

Table 12 shows mean and standard deviation values of tremor related measures in males and females across three levels. Females seemed to show differing trends for frequency tremor related measures (considerable increase in values only in level 1 compared to baseline) and amplitude tremor related measures (considerable increase in values only in level 2 compared to baseline). Whereas, males show considerable increase in all tremor related measures only in level 2 when compared with values in the baseline.

*Table 13: |z| and significance values of tremor related measures*

| Parameters | | \|z\| | Sig. |
|---|---|---|---|
| Fftr | L_B | .601 | .548 |
| | L_1 | .980 | .327 |
| | L_2 | 1.844 | .065 |
| Fatr | L_B | 1.794 | .073 |
| | L_1 | 1.609 | .108 |
| | L_2 | .434 | .664 |
| FTRI | L_B | .350 | .726 |
| | L_1 | .506 | .613 |
| | L_2 | .790 | .430 |
| ATRI | L_B | .954 | .340 |
| | L_1 | 1.531 | .126 |
| | L_2 | .301 | .764 |

* Significance level <0.05; (_B) baseline, (_1) level 1, (_2) level 2

Table 13 depicts the results of Mann Whitney U test which revealed no significant differences between males and females. Comparison between levels was examined through Wilcoxon Signed-rank test. Results indicated that females showed significant differences between baseline and level 1 only in F0 tremor measure ($|Z| = 2.919$, $p = 0.004$). However, males did not show such significant differences for any parameter at any level.

As stated in literature that cognitive load results in inadequate, unbalanced muscular behavior in larynx (Holmqvist, Santtila, Lindstrom, Sala, and Simberg, 2013) is in agreement with the above findings wherein F0 tremor measure has shown a significant increase in level 1 in females. Surprisingly, males did not seem to be responding for cognitive load as females.

In summary, the present study has revealed varying results for acoustic parameters within and across the two genders for different complexity levels.

**Comparison of females and males across complexity levels**

The current study revealed decreasing trend in frequency information measures in high cognitive load condition (level 2). Short and long term perturbation measures showed unusual trends wherein females exhibited increasing trend in RAP, Jitt and sPPQ measures from baseline to level 1 (low load condition) and males exhibited lowering trend from level 1(low load condition) to level 2 (high load condition) which confirms the findings related to physiological alterations that occur at laryngeal level (Deitrich and Abbott, 2012; Yap et al., 2015) when the person is confronted with high cognitive load. Noise related measures indicated both increasing and decreasing trends and interaction effect of gender. Females showed decrease in VTI and increase in SPI in high cognitive load conditions, whereas males displayed decreased SPI measures for the same. Mendoza and Carballo (1998) also report SPI as a quantitative and sensitive measure of the level of cognitive load. Changes occurring in noise related measures are likely resultant of lack of coordination between sub-glottal pressure and medial compression of the vocal folds under high loading conditions as speculated before that cognitive load brings about imbalance and incoordination in the speech sub systems. In addition, short and long term amplitude perturbation measures and tremor related measures revealed no significant changes across complexity levels. Although, short and long term amplitude perturbation measures are sensitive index for detecting laryngeal pathology, it did illustrate any significant changes in induced cognitive load condition.

**Comparison between genders**

When females and males were compared, all frequency information measures, short and long term frequency perturbation measures except Jita and noise related measures showed significant differences between males and females which can be attributed to anatomical and physiological differences existing between them. Moreover, the interaction effect found between levels and gender in these above mentioned parameters strengthen the view that vocal response to cognitive load may be as individualistic and unique as voice itself. Physiological processes inherently governed by the biological sex are one of the major factors that may bring about vast differences in the way the individual responds to such high cognitive load conditions. These varied responses in the individuals can be attributed to the possibility of differences in susceptibility to stimuli and parasympathetic arousals between males and females. Tolkmitt and Scherer (1989) have also reported that arousal levels in males and females are different as they respond to cognitive load differently. On the other hand, no such statistical significance was found between males and females while comparing tremor related measures and short and long term amplitude perturbation measures except APQ.

# CHAPTER V

# SUMMARY AND CONCLUSION

Cognitive load can be considered as a manifestation characterized by highly demanding environment which entails response to an intrinsically less agreeable stimulus. It has often been examined and measured through various speech based measurements in order to quantify its manifestations. The physiological changes that occur also interfere with sub systems of speech and thus laryngeal apparatus. Human voice serves as a sensitive feature which is highly vulnerable to alterations occurring in the immediate environment.

The current study aimed to investigate objective and quantifiable vocal correlates of cognitive load.  A variation of stroop test was specifically designed incorporating time pressure with varying difficulty levels. This test was utilized to induce cognitive load in 50 subjects (25 males and 25 females) ranging in age from 18 to 22 years who participated in the study. The subjects were instructed to phonate sustained vowel /a/ for about 5 seconds prior to the test (baseline) and following an alert signal (beep sound) during the test in each complexity level. These phonation samples obtained in different complexity levels (level 1 and level 2) and baseline were subjected to analyses using Multi-dimensional Voice Profile (MDVP). Statistical analyses were performed considering 23 vocal parameters among other extracted parameters to check the level of significance across complexity levels and between genders. Results obtained were discussed based on 5 major categories of vocal parameters: Fundamental frequency information measures, Short and long term frequency perturbation measures, Short and long term amplitude perturbation measures, Noise related measures and Tremor related measures.

The findings of the present investigation revealed Fundamental frequency information measures as sensitive and quantitative indicator of the degree of cognitive load. In response to cognitive load there were number of significant changes observed in the participants such as decrease in fundamental frequency measures (F0, T0, Fhi, Flo and STD), increase in frequency perturbation measures (Jita, Jitt, RAP, PPQ, sPPQ and vF0) in females which is in contrast to lowering trend found in males and similarly differing trends in noise related measures (NHR, VTI and SPI) for males and females. Outcome of the present study favors the hypothesis that control of the individual over future events diminishes when he/she is confronted to situations like high cognitive load, which would increase the sympathetic arousal level leading to physiological changes such as modifications occurring at the level of vocal folds to compensate for it. Moreover, the significant gender differences found can be attributed to the differential effect that the above mentioned changes are person specific resulting in distinctive responses between males and females.

The present findings add to the growing body of literature, providing a valuable insight on the likelihood of cognitive load acting as a causative/precipitative factor resulting in voice problems. The results in general has shown individuals experiencing variations in acoustic characteristics of voice in response to cognitive demands in the immediate environment leading to the speculation of inherent physiological modifications at the level of vocal folds. Furthermore, differential effect of cognitive load between genders paves the way for future studies to scrutinize the probable sources of individual differences by inclusion of stringent homogenous group of subjects based on age, gender, employment, education level, intelligence quotient, vocal training etc.

### Implications and future directions

The present findings need to be generalized with caution owing to sample size and heterogeneity of the sample, hence providing scope for future researches to investigate the impact of cognitive load on larger group samples, and specifically in professional voice users, individuals with vocal pathologies etc. More investigations need to focus on the extent of susceptibility to resist changes in voice due to cognitive load which may help us in formulating preventive measures for such individuals.

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