"ACOUSTIC ANALYSIS OF VOICE WITH COGNITIVELY INDUSED STRESS"

Reg. No. M9815

A Dissertation submitted as part of the fulfillment of Final Year M.Sc. (Speech and Hearing) to the University of Mysore.

All India Institute of Speech and Hearing
Mysore - 570 006.

MAY 2000

In Fond Memories of
my Dear Mamaji

CERTIFICATE

*This is to Certify that this Dissertation entitled "**Acoustic Analysis of Voice with Cognitively Induced Stress**" is the bonafide work in part fulfillment for the degree of Master of Science (Speech and Hearing) of the student with Register No. M9815.*

Mysore
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CERTIFICATE

This is to certify that the dissertation entitled "Acoustic Analysis of Voice with Cognitively Induced Stress" has been prepared under my supervision and guidance.

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DECLARATION

This Dissertation entitled "Acoustic Analysis of Voice with Cognitively Induced Stress" is the result of my own study under the guidance of *Dr. N.P. Nataraja,* Professor and Head of the Department, Department of Speech Sciences, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any University for any other diploma or degree.

Mysore
May 2000

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INTRODUCTION

Voice plays a major role in speech, and hence in communication. Voice has been defined as the "Laryngeal modulation of the pulmonary air stream, which is further modified by the configuration of the track" (Michael and Wendahl, 1971).

The production of voice is a complex process. It depends on the synchrony between the respiratory, the phonatory and the resonatory systems which in turn requires precise control by the central nervous system. Hirano (1981) states that, "during speech and singing the higher order centers including the speech centres in the cerebral cortex control voice production and all the activities of the central nervous system is finally reflected in muscular activity of the voice organs. This muscular activity is also affected by the emotional state of the individual.

With the ever increasing advancements in the society, the demands placed on the individual have also been growing. This may lead to tension anxiety and psychological stress in an individual. Changes in the physiological state has been considered to be reflected by voice [Scherer 1986]. Voice can then be used as an indicator of the emotional states of an individual. The nature of human vocal apparatus allow for the encoding of emotional and other non-linguistic information (Protopapas and Lieberman, 1996). Studies have found correlations with speaker mood or style in fundamental frequency of phonation, prosodic patterns, and glottal source characteristics, [Scherer, 1986; Murray and Arnott, 1993]

Several..different speaker moods or emotions in their vocal consequences have been investigated, including workload (or task-induced) stress [Hecker et.al, 1968; Streeter et.al, 1983], anxiety [Smith, 1977] and simulated emotions [Williams and Stevens, 1972]. The findings of these studies show discrepancies and are inconsistent. This can be attributed to two major conceptual problems, as given by Scherer (1986);

a) Lack of analytical seperation of different determinants of voice production - physiological, cognitive social, cultural and interactional that may combine with or counteract each other in vocal expression.

b) Lack of precise specification and description of the emotional state underlying the vocal expression, independent of whether it is induced, posed or studied naturalistically.

The relationship between vocal parameters and stress vary widely among subjects and situations, and differences may exist between the induced and natural stress, the type of task used to induce stress, and the proper definition of stress and its quantification. The ultimate aim of the studies examining the parameters in the voice signal that are related to the emotional state of a speaker is to monitor the physiological and emotional state of an individual through analysis of acoustic characteristics of his utterances.

There are several means of anlysing voice, developed by different workers, to note the factors which are responsible for creating an impression of a particular voice. Presently acoustic analysis of voice is gaining more importance because it is non-invasive and provides objective and quantitative data. Acoustic analysis can be done by using methods such as spectrography, peak analysis, inverse filtering, computer based methods and others.

In computer based techniques, there are many programs which are designed to extract different parameters of voice. However, the software program used in this study "Multidimensional Voice Program Model 4305" developed and marketed by Kay Elementries Inc., New Jersey, acquires, analyses and displays twenty nine voice parameters from a single vocalization. This program uses the computerised speech lab hardware system for signal acquisition, analysis and playback. Twenty-nine extracted parameters are available as numerical file or they can be displayed graphically in comparison with a data base.

Need for the Present Study :

Attempts have ben made [Anita, 1994] to study normal adult voice using MDVP. However, no studies have been attempted to note parameters which help in identifying changes in voice due to stressed conditions. Therefore, it has been attempted to find out the acoustical parameters sensitive to cognitively induced stress in normal adults.

A group of 10 normal males and 10 normal females were considered for the study. These subjects were required to phonate vowels |a|, |i| and |u| in the presence of stressloaded instructions (which formed the baseline measure) and in three conditions of cognitively induced tasks (which forms the experimental measures). The parameters of MDVP software were measured for phonation in all the four conditions.

Hypothesis :

There is no significant difference in terms of parameters measured using MDVP between the subjects in the baseline and experimental conditions i.e., Reading of tongue twister task, reading of the tongue twister with DAF task and reverse spelling task.

Limitations of the study :

1) The study was limited to 10 male and 10 female subjects.
2) Measurements was done for all the subjects for only one day and in similar situation and repeated measurements recordings across the days and different situations were not done.

Recommendations :

1) Acoustic parameters can be studied within a large sample of subjects.
2) Repeated measurements/recordings of the same subjects across days and different situations would yield better information about voice quality in stressed conditions.
3) Studies can be done to evaluate voice in the presence of natural stress such as that present in parents of disabled children, exam going students etc.

REVIEW OF LITERATURE

Communication forms the very essence of existence of life. Man is a social animal who can express his thoughts, emotions, ideas etc., using language as vehicle. The spoken word, which forms the speech, is fundamental to civilization. Speech is thus considered as the highest manifestation of human communication.

The underlying basis of speech is voice. It is the musical sound produced by the vibration of the vocal cords in the larynx by air from the lungs. "Voice plays the musical accompaniment to speech rendering it tuneful, pleasing, audible, coherent and is an essential feature of efficient communication by the spoken word" [Greene, 1964]. The voice embraces an extraordinary analogue of personal information, presenting a cameo of life history carved into paralinguistic and linguistic channels.

Voice is more than a means of communicating verbal messages clearly. It serves as a powerful, conveyor of personal identity, emotional state, education and social status. Voice constitutes the matrix of verbal communication infusing all parameters of human speech and the unique self we present to the world. Every voice is unique to a speaker. The distinctive voice quality by which each person is identifiable is dependent upon the anatomical features and the vocal setting giving its permanence. the dimensions of the vocal tract and the resonating system of each individual are unique. They impart the particular vocal quality which distinguishes one individual from all others and by which a speaker is recognised.

Superimposed upon the permanent anatomical voice features is the highly variable range of possible voicesettings. These are the muscular tension adjustments of the vocal tract which are learnt unconciously in the family and later on in the school, social, professional or occupational group. The voice settings, besides the adjustment in the vocal tract affecting tone also include characteristic levels of volume and pitch. They became habitual and there is no awareness of them in majority of speakers but they may be controlled by the individual. The voice transmits a wealth of information concerning the speaker through changes of vocal tone registered in the diverse attitudes evoked by different social contexts.

The term voice has been defined differently by different people. The 'RANDOM HOUSE DICTIONARY' lists 25 primary and secondary definitions of voice. The first of which is, the sound or sounds uttered through the mouth of the human beings in speaking, shouting, singing, etc.

Some definitions of voice restrict the term to the generation of sound at the level of larynx, while others include the influence of the vocal tract upon the generated tone and still others broaden the definition by including aspects of speech like articulation and prosody.

Voice is the sound produced primarily by the vibration of the vocal folds and does not include anything about resonance [Travis, 1957]. Fant (1960) has used the formula P = ST in which the speech sound P is the product of the source S and the transfer function of the vocal tract (T). While discussing the production of speech it should be noted that the source S of the formula P = ST is an acoustic disturbance, superimposed upon the flow of respiratory air and is caused by a quasi periodic modulation of the air flow due to the opening and closing movement of the vocal fold.

According to Aronson (1980) voice can be definied as the audible sound produced by phonation. Michael and Wendahl (1971) after reviewing various definitions of voice define voice as the laryngeal modulations of the pulmonary air stream which is then further modified by the configuration of the vocal tract. Green (1980) states that voice is the result of breath under pressure from lungs causing the approximated vocal cords to perform the rhythmic excursion of separation and closure.

A study of various definitions available, indicates that the pulmonary air stream (acting) as a power supply, the participation of the vocal cords (vibrator) and the vocal tract transfer function (resonator or modulator) are common among them. Therefore any definition of voice must include these three aspects.

The elements of voice as stated by Aronson (1980) are: pitch, loudness, quality, flexibility. Pitch is the perceptual correlate of frequency whereas, loudness is the perceptual correlate of intensity and quality is the perceptual correlate of complexity. Flexibility is the perceptual correlate of frequency, intensity, complexity variation. Flexibility is not frequently used to describe the voice. It is more difficult to definie normal voice than any other speech or language component because by nature, voice variety is limitless and the standards of voice adequacy are broad.

Johnson, et.al, (1956) states the general standards for normal voice as follows:

1. Quality must be pleasant. This criterion implies the presence of a certain musical quality and absence of noise.
2. Pitch level must be adequate. The pitch level must be appropriate to age and sex of the speaker.
3. Loudness must be appropriate. The voice must not be so weak that it cannot be heard under ordinary speaking conditions nor it should be so loud that it calls undesirable attention to itself.
4. Flexibility must be adequate. Flexibility or variety refers to variations in pitch, loudness that aid in the expression of emphasis, meaning, subtleties indicating the feelings of the individual.

Wilson (1962) is of the opinion that good voice should have the following characteristics.

a) Pleasing voice quality
b) Proper balance of oral and nasal resonance
c) Appropriate loudness
d) A modal frequency level suitable for the age and sex
e) An appropriate voice reflections involving pitch and loudness.

An attempt has been made by Nataraja and Jayaram (1975) to review the definitions of normal voice critically. They have concluded that each of the avilable defintions of voice have used subjective terms which are neither definable or measurable.

They have suggested a possibility of defining good voice operationally. The good voice is one which has its optimum frequency as its fundamental (habitual frequency).

A voice disorder exists when quality and/or pitch or loudness diffr from voices of others of similar age, sex, cultural group [Wilson, 1962]. The importance of the human voice in modern society cannot be overstated. It is the primary instrument through which most of us project our personalities and influence our compatriots. Voice has both linguistic and non-linguistic functions in any language.

Voice is the carrier of speech, variations in voice int erms of pitch and loudness provide rhythm and also break the monotony. This function of voice draws attention when there is a disorder of voice. Voice plays a crucial role in the linguistic conveyance of meaning in non-segmental phonology.

Voicing (presence of voice) has been found to be a major distinctive feature in almost all languages. Voicing provides more phonemes and makes the language broader.

At the semantic level also voice plays an important role. The use of different pitches, high, low with the same string of phonemes would mean different things. Speech prosody or the rhythm of language is a function of vocal pitch and loudness as well as of phonetic duration.

In contrast to the long term nature of the anatomy and voice settings which combine to make voice permanence, there are paralinguistic features of voice which change with emotion. Shades of feelings are reflected in the voice and are inextricably linked with the verbal message and may over-ride it.

These features are recognised as TIMBRE, TONE OF VOICE. Cry sal (1980) refers to them as voice qualifiers.

The most primitive use for voice is SURVIVAL. Expressions of hunger are often vocal especially by infants. Both hunger and pain cries are intense and have a quality that is difficult to ignore. They evoke sympathy and desire to assist. Other cries are used for defensive purposes.

Perkins (1971) has identified at least five non-linguistic functions of voice. Voice can indicate speakers

1. Physical health
2. Emotional health
3. Personality
4. Identity
5. Aesthetic orientation

Lass, Brong, Ciccolella, Walters, Maxwell (1961) report several studies which have shown that it is possible to identify the speaker's age, sex, race, socio-economic status, racial features, height and weight based on voice.

Expression of emotions is highly vocal. Six primary emotions-fear, anger, joy, sadness, surprise, disgust are expressible vocally. Huttar (1966) has concluded that voice reflects the emotional conditions reliably.

Inferences can be drawn from voice quality about a speaker's personality. Traits such as kindness, honesty, cheerfulness may all be associated with special vocal characteristics.

Loudness is a parameter of voice which varies from one individual to another and will vary at different times within the same individual according to the emotional or linguistic content of the communication. Increasing loudness is an effective way of establishing the speaker's turn in a conversation and will deter the intervention of other speakers.

Another function of voice is to reflect the physiological state of the individual. 'Voice is a window' to many functions (normal or abnormal) performed by the body. Hoarseness can be an indicator of viral infection; tremor in voice is an early sign of neurologic disease. Strangled voice can result from e otional trauma. It is a well known fact that voice basically reflects the anatomical and physiological conditions of the respiratory, phonatory and resonatory systems, i.e., deviation in any of these systems may lead to VOICE DISORDERS.

A recently developed aspect in the area of early identification of disorders is INFANT CRY ANALYSIS. It has been found by Indira, 1982, that it is possible to identify abnormalities in the neonates by analyzing their cry. A number of professionals like singers, teachers, actor, radio/TV announcers, attorneys rely on voice as a primary tool of trade. A description of paralinguistic aspects of voice is not complete without acknowledging the part played by non-verbal communication. From the purely physiological view point, body postures change the tensions and the dimensions of the resonators and therefore reflect what is beneath the verbal signals. Facial, hand, arm gestures are integral parts of communication which vary between individuals, social and ethnic groups. There are also differences in the same individual according to mood and relative degree of formality in a situation. In general, movements are less animated when an individual is depressed or relaxed.

The production of voice depends on the synchrony or the coordination between the above systems, i.e., RESPIRATORY, PHONATORY AND RESONATORY. Respiration is usually defined as the process of exchange of gas between an organism and an environment. Two phases in respiration have been recognised, i.e., inhalation and exhalation. Idol (1936) from her investigations arrived at the conclusions that:

There is a tendency for those subjects who habitually breathe deeply for life purposes to breathe deeply during phonation. More than half of the subjects breathe more deeply for life purposes than for normal speech. Approximately one-third of the subjects breathe more deeply for normal than for loud speech. Upto the present time, no measurable aspect of casual breathing or of breathing during phonation has been found which by itself affects the vocal characteristics.

Voice production involve a complex and precise control by the central nervous sytem of a series of events in the peripheral phonatory organs. The crucial event essential for voice production is the vibration of the vocal folds. It changes DC air stream to AC air stream converting aerodynamic energy into acoustic energy. The broad categories of theories have demonstrated in dealing with voice production. They are :

Myoelastic-Aerodynamic Theory :

The proponent of this theory was Muller 91943). Minor modifications were suggested by Smith (1954) Periodic opening and closing of the vocal folds is produced by an interaction between mass, tension of the vocal folds and the aerodynamic forces exerted on and around them by the exhaled air stream. The theory's main contention is that vocal folds adducted and held passively in the midline are opened and closed due to the infraglottic air pressure. The theory can be explained in detail aas follows:

1. The vocal folds are adducted to the midline and are firmly held there.
2. As the air stream is forced from the lungs, sub-glottic pressure rises to a level that overcomes the resistance of the adducted vocal folds and consequently they open momentarily releasing a puff of air.
3. At this moment air stream is flowing through an hour glass shaped, cross sectional area, the wider ends formed by subglottic trachea and supraglottic pharynx with the middle being a narrower channel bounded by true and false vocal folds.

4. The air pressure within this narrower channel falls during momentary flow of air through it owing to the Bernoulli effect. As suction produced by a drop in pressure in the region of the folds plus the static tissue forces begins to counterbalance the subglottic pressure from the lungs, folds begin to move inward, the narrowing channel causing an increase in suction until the folds snap shut. This completes one vocal fold cycle and the folds are now in a position for the cycle to repeat itself [Wilson, 1962].

Neurochronaxic theory [Husson, 1959] holds that vocal fold vibration is an active process. The vocal folds rather than being passively forced open and closed periodically do so actively by means of rhythmic contractions of the vocalis potion of the thyroarytenoid muscle. Motor impulses are said to be emitted from cortical centres to the muscles of the folds via the recurrent laryngeal nerves under the regulation of cochlear recurrential reflex! The contractions of the vocalis portion of the thyroarytenoid muscle are alleged to occur at the same rate as the fundamental frequency (F_o). Vocal fold stimulation of this kind assumes that recurrent nerve is capable of transmitting high frequency stimuli, i.e., of the order of 1000 impulses per second.

It has been established that the coordination between the three systems respiratory, phonatory, resonatory are essential for the production of voice. Variation in the conditions of these three systems would be reflected in the voice produced.

Persons in occupations that place a high demand on vocalization are often considered to be at risk for the development of voice problems. Rock singers, actors attorneys, teachers and other persons who use their voice vocationally often involve in vocal ovemse or abuse, they form the high risk group to develop voice problems [Sapir, et.al, 1992].

A voice disorder exists when quality and/or pitch and/or loudness differs from voices of others of similar age, sex, cultural groups.

The question of normality and abnormality of voice is a matter of subjective opinion therefore most of the classificatory systems of voice and its disorders have been rendered ambiguous. A classification based on etiology have been employed by many [Moore, 1971, Van Riper and Irwin (1966)] The problems which are perceived as abnormal pitch, loudness or quality may be directly related to the mechanisms of the respiratory, phonatory, resonatory systems, when there is a voice disorder it would mean that one or more of the systems., i.e., respiratory, phonatory, resonatory are not functioning normally, either because of structural or physiological conditions or due to faulty learning.

Another frequently used classification of voice disorders is based on the three attributes of voice-pitch, loudness, quality [Perkins, 1971].

Boone (1977) classifies voice disorders based on changes in vocal fold mass size and approximation.

Aronson (1980) has classified voice disorder as organic and psychogenic or functional type. According to him, a voice disorder is organic if it is caused by structural (anatomic) or physiologic disease either a disease of the larynx itself or remote systemic illness which impair laryngeal structure or function. Psychogenic voice disorders include disorders of quality, pitch, loudness, flexibility caused by psychoneurosis, personality disorders or faulty voice usage.

Modern Technology has produced machinery that requires the human operator to perform complex tasks under hazardous conditions. The resulting psychological or physiological stress may reduce his normal proficiency and limit his physical abilities. Although it is recognized that performance often involves some form of verbal communication, few studies have considered the possibility that speech may serve as an indicator of stress [Ruesch and Prestwood, 1949; Ostwald, 1965]

Various definitions of stress have been employed in earlier studies. Selye (1956) defined stress as a condition of altered homeostasis in one or more systems, and this condition can be produced by factors in person's psychological as well as physical environment. Thus, according to him the process of living is a series of attempts to cope with various stressful situations. In other words, stress refers to people's reaction to situations that pose demands, constraints, or opportunities [Soroson, 1981]. People are likely to experience psychological stress when they have to deal with an unexpected or unusual change. They are likely to experience even greater stress than usual when the change occurs at the same time as a severe life crisis (such as the death of a loved one) or at the beginning of a critical developmental period (such as adolescence). Stress is thus any condition or state in which life support or adaptive process are threatened. It is different from the experience of distress which means feelings of pain, fear, depression, grief and the like [Mahony, 1963]. Hollien (1990) observed that states as disparate as hostility, anger, fear, anxiety, as well as deception and divided behaviour, and even psychopathological states, might be considered under the general rubric of stress evaluation. Hollien gave the definition of psychological stress as a psychological state which results as a response to a perceived threat and is accompanied by the specific emotions of fear, anxiety, and/or anger.

A stressor is an event or situation which challenges the adaptive functioning of the body and thereby induces a condition of stressors. Sound is considered as one of the mechanical stresses. Also one's thoughts and images can induce stressors, as in the case of nightmares, through electrochemical processes which upset the body's balance. The role of cognitive and perceptual mechanisms in stress is very important as many of our modern stressors are at least partially influenced by the individual's perception of them [Lazarus, 1966; Lipowski, 1973]. The cognitive patterns may not only influence how one perceives a stimulus, but also how one reacts to it. If one is confident about one's academic abilities, for example, a low quality in a course might be less stressful [Mahony, 1963], than if one thinks that one's whole future and entire self-worth hinge on the grade one receive. Different studies have used different stresses to induce stress. Hecker et al, 1968, developed a task involving, the addition of numbers under time pressure. If shock is discarded as the classical generator of stress, one finds that most of the experimental studies have used tasks of cognitive workload, understood as the proportion of available cognitive resources dedicated to performing a task [Kantowitz & Sorkin, 1983].

The assumnption that the tasks of workload produce reliable effects in the acoustic parameters of voice has been supported by various studies that have evaluated the effects of psychological stress on voice. There has been a tendency to consider cognitive workload and psychological stress as equivalent, which has made it difficult to differentiate the acoustic changes due to stress from those due to the task itself [Lively, et al, 1991]. The mental load has generally been induced with orders to speak more quickly, with more clarity, or through lombard conditions. Ellson, et.al, (1952) employed a delayed auditory feedback stressor presented to the subject while he was reading aloud prior to testing. In other cases, inverse spelling [Martin and Talavera, 1990] or verbalization during logical problem solving [Tolkmit and Schrer, 1986] have been used to induce stress. In general, all of these paradigms require the subject to simultaneously perform two tasks that demand attention. It is presumed that the greater the difficulty of the task and the greater the demands to speak, the greater the interference will be.

Mendoza and Carballo in 1998 used reading of tongue twisters, reading of tongue twisters with delayed auditory feedback (DAF) and reciting the letters of the Spanish alphabet in inverse ordere as tasks that required a high degree of attention during verbalization.

Delayed auditoiy feedback (DAF) refers to an experimentally induced delay in air conducted auditory feedback and has been reported to produce stuttering like behaviour [Lee, 1950]. Venkatagiri (1980) concluded that there are certain fundamental similarities between dysfluencies produced under DAF and stuttering. Nataraja, Rajkumar and Ramesh (1983) reported that females show more number of blocks while reading. However males do not show much differences in terms of number of blocks while reading the passages under DAF. They also reported an increase in Fo and intensity and also slower rate of speech under DAF conditions.

With each new stressor, one may develop adaptive or maladaptive stress reaction patterns. The stress reactions of the person's responses to a stressor may be divided into four inter dependent categories [Mahony, 1963].

These four categories may be :

1. Psychological responses)eg., increase in pulse, blood pressure, respiration and perspiration etc.).
2. Emotional responses (eg. fear, anxiety, anger, depression, joy et.c)
3. Cognitive responses (eg. thoughts, images, dreams, coping strategies).
4. Behavioural responses (eg. approach, avoidance).

Saroson, classified these reactions of stress in three categories. These are :

1. Bodily responses (eg. rapid pulse, heartbeat, increased perspiration, tension, shortness of breath, gritting of teeth etc.)
2. Psychological responses (eg. feeling upset, inability to concentrate, worry, anxiety, irritability, lack of self-confidence etc).
3. Behavioural responses (eg. smoking, alcoholism, accident proneness, disturbed sleep and eating patterns).

One of the psychological responses of the body due to stress is an increase in pulse. This increase in pulse initiates a parasympathetic action and adrenalin is released which in turn leads to increase in muscle tone [Mahony, 1963]. Thus various researchers have shown changes in the voice quality due to stress.

Scherer (1986), reviewing acoustic phonatic findings on vocal affect, proposed a "sequence theory of emotional differentiation". This takes into account the physiology of speech production and the physiological effects of emotional status. According to Scherer's theory, stimuli are evaluated according to functionally defined criteria, such as "novelty", "need", "coping potential", etc. The net result of the outcomes of all evaluation checks affects the nervous system. In turn, the physiological consequences of the nervous systems response define the changes in the voice characteristics that carry the emotional information. For example, unpleasant stimuli causes "facial and pharyngeal constriction and tensing as well as shortening of the vocal tract", leading to stronger high frequency resonances, a rise in the first formant, a fall in the second formant, narrow formant bandwidths, etc. However individual variability was also reported.

Various studies also have been done regarding the voice changes due to physical stress. The most common symptoms reported of physical stress is vocal fatigue. It is usually described as a negative sensory vocal sympton that corresponds to a change in vocal quality or a change in vocal response [Sataloff, 1984].

Signs **of Vocal Fatigue** :

Body language of vocal fatigue consists of frequent licking of lips, attempts to alternate tension in the face, neck, shoulders.

- Compromise in posture
- Hoarseness, excessive throat clearing
- Loss of intensity on extremes of pitch range
- High and low notes becomes weaker
- Special signs of vocal fatigue in signers are lack of ability to sustain long phrases, loss of tone focus and irregularity in vibration.

Physiological limitation for vocal endurance may be selected to the following phenomena. Fatigue of laryngeal muscles that normally provide tension in vocal folds and stability of the larynbgeal configuration, straining of non muscular laryngeal tissue. Increase in tissue viscosity of vocal folds making it hard to mainteain vibrations because of increased internal functions. This may be the result of dehydration or chemical changes in fluid compositions. Loss of blood circulation due to constricted blood vessels in phonation. this may impede the regenerative processes and reduce the systems capacity to transfer heat away from vocal folds to surrounding tissue. Loss of sub-glottal pressure caused by fatigue of respiratory muscles.

Raphael and Scherer (1986) found that 36 professional actors associated the following symptoms with vocal fatigue-general physical fatigue, throat fatigue, throat tightness or constriction, strained or tense throat, greater awareness of voice and its mechanism, more difficulty in producing the sustaining voice, reduction in pitch range and more difficulty in producing higher pitches.

According to Gelder, Marks (1987), among aerobic instructors there is increasing concern that vocal abuse and vocal injury may occur at a high prevalence level. Early warning signs have not been identified or are often ignored leading to the development of vocal fold pathologies which may require therapy, surgery or long periods of vocal rest.

Heidel and Torgerson (1993) used questionnaire to determine the characteristics of vocal problems. It was distributed to 75 female aerobic instructors and 75 female aerobic participants ranging from 20-40 years. The questionnaire included pertinent questions relative to length of teaching, participating experience/average number of classes taught, type of aerobics, participated sequentially, history of vocal problems, water intake daily during instructing, sleep, smoking habits. The results indicated that aerobic instructors experienced more hoarseness episodes of voice loss during or after instructing, higher prevalence of modules. The results suggest that aerobic instructors experienced a higher prevalence of vocal problems when compared to individuals participating in aerobics.

Ohlsson, Jarnholm, Lofquist 91987) did a study to assess vocal behaviour in welders. Subjects were given 20 questions concerning professional demands on voice as well as vocal problems, hoarseness, aphonia, sore throat. Questions were asked about vocal effort in order to be heard at work.

Eight welders and eight clerks were selected (exposed to noise level of 95 dB at place of work). A tape recording was made of each subjects reading aloud of a standard test and sustained phonation of |a|. These recordings were judged by a panel of five trained speech pathologists on a 11 point scale. The results revealed that voice and throat problems were more frequent among welders than among clerks. The results of the listeners judgement Welders voices as hyperfunctional, unstable and clerks voice as hypofunctional stable. hi summary noise exposure may be a major contributing factor for voice problems among welders. The contribution to vocal symptoms from other factors like welding fumes, dust, gas should also be taken into consideration.

The physical demands on a singer can be very great if one considers the energy needed in performance as well as the wearing life style inherent in the profession.

Arnold (1965) states that untrained singing voice will have a range of one end and a half to 2 octave while trained singer may exceed their limits as much as one octave.

The singer uses increased effort in an attempt to project the voice. In addition, the singers surroundings are noisy, dusty, smoky. Some performers take alcohol or drugs in order to give an uninhibited and confident performance. These substances will exacerbate the effects of vocal abuse. Correct voice production in these singers prevents breakdown.

Singers even the most successful ones are found to be anxious before performance and the emotional volitility and temparament is well known. Their anxiety aggravate the vocal symptoms and they need sympathy and understanding [Punt, 1963]. According to Zilstorff (1968) trained singers can in emergencies sing with a cold and infective laryngitis. The untrained or poorly trained singer with signs of vocal abuse and chronic laryngitis should never do so. The performance will be disastrous and not only aggravate the condition but also be psychologically traumatic.

Many singers distinguish between their speaking voice and singing voice but for the purpose of avoiding vocal abuse it is important for the singers to be aware that everyday habits of vocal abuse when speaking will be reflected in the singing voice. A singer, practising for several hours can indue oedema of the vocal folds from overuse and function some light hoarseness. Usually the singer is doing one of the two things.

Overblowing:

Putting excessive air pressure on the vocal folds or too much muscular effort in the larynx to produce sounds. While these faults will cause chronic hoarseness, long range effects with such faulty techniques can lead to vocal nodules, polyps, hoarseness, fatigue. Habit forming and drugs like heroin, cocaine, tranguilizers alter emotional sensitivity and lead to hoarseness. Since a sensitive performance demands all one's faculties to be at their keenest in the long run, drug addiction dooms the singer to failure.

Dmiterei and Kesiler (1979) did a study to find the relationship between the formant structure of different types of singing voice and dimensions of supra glottic structures. In the process of training voice of an opera singer a correct timbre in the whole voice range plays a great role. Integrated spectra of different types of singing voice were obtained. Each type if characteristic of a certain frequency range for high and low singing formants. There is a clear correlation between acoustic characteristic and length of the buccopharyngeal tract. The physiological adaptation of larynx during opera singing is determined by acoustic necessity to have a typical timbre, therefore during voice training one must start with searching for a characteristic phonation.

According to Greene (1980) singers who are properly trained and who uses the technique of good voice production do not damage the vocal folds. According to Bunch (1982), a singer may have some vocal strain following lengthy rhearsal or demanding performance. A tiny vocal fold haemmorage may occur but will gradual disappear when exertion is over. However if voice is poorly produced and excessive effort is being used in an attempt to project it or achieve ntoes above or below the natural range, the long term damage will be damage to laryngeal mucosa and eventually vocal nodules.

Peter Watson and Hixon (1985) did a study on the respiratory kinematics of opera singer. They found that the subjects descriptions of how they thought they breathed during singing borte little correspondence to how they actually breathed. Implications for training of singers are offered. Vocal abusers and 25 female subjects without a history of vocal abuse were compared employing the Goldman Frista Woodcock test of selective attention. The vocal abuse population was found to be significantly poorer in discrimination abilities than the control group. Vocal abusers unable to discriminate their own speech in a noisy environment increases vocal intensity and thus increases chronic abuse of the vocal mechanism. The implications of this study are that speech discrimination testing in noise must be routinely done for vocal abuse population.

Vocal fatigue:

Most attempts to study vocal fatigue habve been carried out in the laboratory situations.

Holsbrook (1977) is one of the few investigators who have reported studies of speakers in their day-to-day activities. In all this studies a portable vocal intensity indicator was used to measure the duration for which subject vocalizes or the amount they vocalize above selected intensity level. He looked at the amount and loudness levels of teacher's vocalization during work days. He concluded that the amount of vocalization and the percent of vocalization at high loudness level may be related to occurrence of fatigue.

In another study he collected similar data from groups of teachers, students, singers and concluded that those who experiences fatigue talk louder and longer than their peers.

In a third study he obtained the same measure from small groups of students of vocal music. He concluded that the percentage of speaking done at high loudness level may be related to occurrence of vocal fatigue. According to Sanders and Ripich (1983) faituge may be an important factor in further voice deterioration as the speaker struggles to cope with the difficulties by forcing his voice even more.

Neils and Yairi (1987) did a study to investigate physiological, acoustical and perceptional correlates of vocal fatigue. They chose nmoise as the means of creating conditions likely to induce vocal fatigue because of its reflexive effects on loudness, pitch. A 45 minutes reading under noise was carried out. Voice quality did not change significantly overtime according to a panel of listeners. A significant finding was that peak air flow values increased between the inhibition and end of 45 minutes reading period.

H'eth, Trunchon-Gagon and Bilodean (1990) state that the teachers complained of vocal fatigue as not only they used their voice for many hours but in many schools, they have to raise and strain their voice constantly to overcome poor acoustic conditions such as class room noise and room reverberation.

Gotaas, Starr (1993) did a study to assess vocal fatigue among teachers. Recordings were made at the beginning and end of work days of teachers who experienced vocal fatigue (n = 22) and those who did not experience vocal fatigue (n = 17). Those who experienced fatigue were recorded on days in which they did and did not feel the fatigue. Both groups evaluated their vocal characteristics each time they made a recording. Subsequently a panel evaluated the recordings. Both groups estimated amount and characteristics of their talking time, completed a psychological evaluation and provided medical histories. The data was interpret as indicating that the vocal characteristics of teacher who fatigue and those who do not fatigue are similar on days the former group did not fatigue and that the two groups are similar in the amount and loudness of their talking time at work and at home. However teachers who fatigue tend to spend more time in activities that appear to be vocally demanding and are more likely to perceive situations as being anxiety producing. Teachers who fatigue tend to be in good health but have had more hearing problems and allergies than their colleagues and most of their family members have had voice problems.

Based on these findings, it appears that work day activities may contribute to the development of vocal fatigue in teachers regardless of the state of their language or vocal styles.

-Psychological factors may play a role in fatigue development. There are some studies indicating that there are wide individual differences in symptom change over a period of prolonged phonatory task thought to induce fatigue.

Sherman and Jensen (1962) reported vocal strain in their subjects over the half hour of oral reading but adapted so well following that period and felt that they could continue reading indefinitely.

Stone., Scharf (1973) found that the prolonged reading at different pitches and intensities, maximum voice quality change occurred in the first 5 - 10 minutes of phonation after the subject apparently adopted to the vocal task. The above findings suggest that the initial wanning up or vocal adaptation/adjustment period takes place during prolonged phonatory task.

The recoveiy of voice during the rest period after prolonged phonation may be experienced differently by different subjects. There have been quantitative studies in vocal fatigue to chart directly or indirectly physiological changes due to phonation overlong periods of time.

Breiss (1960) concluded that 15 seconds of noise exposure at levels between 70 and 100 dB were sufficient to induce vocal fatigue symptoms. Recoveiy time varied from 10 seconds for normal subjects to one hour for subjects with histories of voice problems.

Sherman and Jensen (1962) have reported that perceptional study suggested normal readers tended to decrease vocal harshness rating at the end of 1 ½ hours with a subsequent increase in harshness rating at the end of a ½ hour vocal rest period. Brodnitz (1971) has used LTAS in evaluating voice fatigue. There were changes in spectral tilt. Sander and Ripich (1981) have reported that a 10 minutes speaking task at 96 and 102 dB did not produce vocal fatigue for majority of speakers. Zagdruiko and Zambovstev (1982) found that after four hours of reading aloud (with short breaks no longer than 10 minutes) reading syllable rates for male and female speakers decreased by 22 - 73 percent.

Neils, Yairi (1987) tried to follow changes of vocal fatigue by means of an acoustic method. They described changes in vocal fatigue in students after a standard oral readingby means of LTAS. There were changes in the spectral tilt. This is in agreement with the findings of Lofquist and Manderson (1987).

Scherer et al. (1986, 1987) reported that non-professional speaker and professional speaker showed no profound changes in jitter and shimmer after several hours of continuous oral reading even though subjects felt fatigued. Titze et al.(1986) have used vocal perturbation measures in an attempt to obtain physiological interpretation of vocal fatigue. A vocally trained subject and a vocally untrained subject read a text at high loudness level with a pitch one octave above their lowest pitches. Acoustic measures and subject's responses to questions about sensory and psychological eactions were obtained. The trained subject produced vocal fatigue symptoms but no significant changes in the acoustic measures over 1½ hours. The vocally untrained subjects reported vocal fatigue symptoms in addition went through a vocal warming up resulting in adaptation to the taks as well as significant change in acoustic measures over 1½ hours. The change in shimmer was correlated significantly with the subjects self evaluation of the relative conditions of their voice. The jitter measure remained high during the rest period, whereas the shimmer values recovered to prefatigue levels.

Geffer et al. (1991) reported similar results like Scherer results but greater difference between trained and untrained vocalists. Trained vocalists did not fatigue as easily on simple vocal tasks. More acoustic dimensions used to be probed to establish predictions of vocal fatigue. Novak and Odlouha (1991) studied vocal fatigue after theatre performance in actors. They used LTAS for the evaluation of vocal fatigue. They performed tape recording of voices of actor, actress for a few minutes before and after theatre performance. All read standard text. Spectral analysis was made in the laboratory. 45 subjects were evaluated in the study. The results revealed changes in skewness of straight line of cormant regions. There were no changes in F_o in men and women. The difference in the shift of F_o between men and women is statistically significant at 5% level. There were no changes in voice by subjective evaluation except in three men.

There are several factors that can induce vocal fatigue.

1. Voice effort and physical effort of performance, acoustic characteristics of the hall.
2. Mental effort of the speaker, professional quality of speaker forcing the voice.

Gopalkrishna (1995) studied vocal fatigue in teachers and investigated the acoustic correlates of vocal fatigue in them.

> Susceptibility criteria for vocal fatigue among teachers.

-> To highlight the sensitive parameters in MDVP for measurement of vocal fatigue.

The results are :

1. The parameters considered sensitive to vocal fatigue were frequency related measurements, frequency perturbation measurements, long term amplitude perturbation measures, noise related measurements were affected.
2. Half hour of reading was sufficient to induce vocal fatigue both in normal and teacher as changes were seen in acoustic parameters.
3. Female subjects showed more number of parameters affected than male subjects.
4. Teachers showed more number of parameters affected across groups than normals.

It can be concluded that teachers were more susceptible for vocal fatigue than normals.

Shobha Menon (1996) did a study to evaluate vocal fatigue in professional voice users and analyse their voice. The results showed :

—> In the frequency parameters only measurement of extent of fluctuations and fluctuations per second showed significant differences between the pre-fatigue and post-fatigue conditions.

-> In the intensity parameters, mean, maximum and minimum of intensity, speed of fluctuations and extent of fluctuations showed significant differences.

Thus, people with physical stress are those susceptible to voice disorders. However, there are fewer studies regarding the voice changes due to psychological stress.

Hecker et al (1968), in their study of acoustic speech signal due to task induced stress showed that most of the changes produced due to task, induced stress are attributed to modifications in the amplitude, frequency, and detailed waveform of the glottal pulses. Other changes result from differences in articulation. The durations of phonetic segments can be altered, and the precision with which articulatory targets for vowels and for consonants are reached can be affected. Stress can also influence the amplitude of the glottal pulses (level), the average rate at which the pulses are generated (fundamental frequency), the contour of fundamental frequency during an utterance. They also said that utterances produced by a given individual while he is under stress will usually exhibit, only some, and not all of these effects. Also the acoustical characteristics associated with the given effect of stress for an individual may be quite different from those for another individual.

William and Stevens (1972) suggested that an increase in respiration rate due to stress, would result in an increased sub-glottal pressure during speech. This heightened sub-glottal pressure would give rise to a higher fundamental frequency (F_o) during voiced sounds in speech. According to them, the increased respiration rate could also lead to shorter durations of speech between breaths, with a consequent effect on the basic temporal patterns of peech. Under some physiologic changes such as excessive salivation, three will be irregularities in the waveform of the glottal output from one pulse to the next.

Ostwald (1965) plotted decibles as a function of frequency to obtain sound energy spectra of the voice, and exposure to the olfactory stiessor of ammonia resulted in decreased energy in the half-octave band centered at 500 Hz. However, ammonia may have affected the mucous membranes of the nasal passages and throat, and the change observed may not have been produced by psychological stress.

Fo selected parameters, including short-term perturbations, long-term variability and mean value, are among the measures often reported to correlate with elevated levels of speaker emotional stress, either task induced or in real life emergencies [Protopapas and Lieberman, 1997].

Scherer (1986) reported in his review that the mean fo and the variability of Fo have been found to increase in situations of fear/terror; his model of vocal affect predicted such changes through the stimulus evaluation checks and their physiological consequences.

Protopapas and Lieberman (1997) concluded that mean and maximum Fo are the salient Fo measures that convey emotional information at least for the extreme kind of emotional stress.

Brenner, et al (1983) believed that the percentage of jitter decreases in direct relation to the level of stress. They associated the decrease of jitter to an increase in the contraction of cricothyroid muscle whichproduce a change in the regularity of vocal fold vibration. Hecker et al (1968) also pointed out that vocal jitter may be a better indicator of stress than fundamental frequency

In contrast, Fuller etal (1992) found increased jitter to be an indicator of stressor provoked anxiety. Protopapas and Lieberman (1997) in their study revealed that jitter does not affect perceived emotional stress. They, thus concluded that jitter may be an indicator of emotions but perhaps not a consistent correlate of extreme stress or terror. In particular, jitter may serve to distinguish between states of low-level anxiety or task-induced stress [Fuller et.al, 1992]

However, in all of the aforementioned studies it was evident that the acoustic correlates of emotional stress in the human voice are subject to large individual differences. Streeter et.al (1983) concluded that there are "no reliable and valid acoustic indicators of psychological stress".

Studies have also been carried out on deception induced stress. Although listener's subjective judgements have been found to be inadequate for discriminating description on the part of a speaker [Fay and Middleton, 1941; Oleclowski, 1967] electronic voice analysis has shown promise. Alpert, Kurtzberg, and Friedloff (1963) filtered, rectified and demodulated voice signals to obtain a measure of voice intensity in a low band (100 - 250 Hz) and a full band (100 - 6,000 Hz). Although voice intensity did not differ during deception when using the full band, it was significantly greater during deception when the low band was used [Podlesny and Raskin, 1977].

The psychological stress evaluation (PSE) developed at Dektor counter intelligence, Virgina, measures deception induced stress in the voice. PSE records physilogical tremor of the vocal muscles occurring in the 8 - 14 Hz region and the strength and pattern of that activity are inversely related to the degree of psychological stress. PSE analysis involves several modes of signal processing and appears to consist mainly of pattern analysis.

Mendoza and Carballo (1998) conducted a study to determine the acoustic effects on voice of three tasks of cognitive workload and their possible relationship to stress. Acoustic analysis was used to measure stress and workload in four experimental tasks and two experiments. In the first experiment, subjects performed cognitive workload tasks under a stressful condition, performing the tasks as rapidly as possible without errors and with the knowledge that any errors committed would reduce their grade in a course. The second condition was to perform the same tasks but without the condition of stress related to the final grade. Four testing conditions were included. One was a baseline measure in which subjects spelled the Spanish alphabet. The second was the reading of a tongue twister, the third was the reading of a tongue twister with delayed auditory feed back, and the fourth was spelling the Spanish alphabet in reverse order. In each condition the subjects prolonged the vowel |a|, for approximately 5 sec. All subjects performed a test to determine their overall level of anxiety. The results suggest that in condition of experimentally induced stress there is an increase in the fundamental frequency (fo) relative to the baseline, an increase in jitter and shimmer, an increase in the high-frequency harmonic energy, and a decrease in spectral noise.

However few of these studies indicate that voice can be an indicator of psychological stress.

Diagnostic Procedure:

Diagnostic procedures for voice disorders comprises of tests that elicit information regarding the actual process of voice production and the nature of the sound generated. The purpose of diagnostic procedures were :

a) To determine the cause of a voice disorders.
b) To determine the degree and extent of the causative disorder.
c) To evaluate the degree of disturbance in phonatory function.
d) To determine the prognosis of the voice disorder as well as that of the cause of the disorder.
e) To establish a therapeutic program.

Michael and Wendahl (1971) consideres voice as a multi-dimensional series of measurable events, implying that a single phonation can be assessed in different ways. They present a tentative list of twelve parameters of voice most of which can be measured and correlated with specific perceptions while others are more elusive and difficult to talk about in more than ordinary terms. The twelve parameters listed by them are :

1. Vital capacity
2. Maximum duration of controlled sustained phonation.
3. Modal frequency range.
4. Maximum frequency range.
5. Maximum duration of sustained phonation.
6. Volume/velocity air flow during phonation.
7. Glottal wave form.
8. Sound pressure level.
9. Jitter of the vocal signal.
10. Shimmer of the vocal signal
11. Effort level (vocal)
12. Transfer function of the vocal tract.

Jayaram (1975) made an attempt to develop a method of differntial diagnosis of dysphonics based on the measurement of the following parameters in normals and dysphonics.

1. Optimum frequency
2. Habitual frequency
3. Frequency range
4. Maximum phonation duration
5. Vital capacity
6. Mean air flow rate
7. Vocal velocity index

Hirano (1981) did an international survey and has recommended the following measures for clinical voice evaluation.

I. a. Air flow
   b. Phonation quotient
   c. Vocal velocity index.
   d. Maximum Phonation time.

II. a. Fo range
   b. SPL range
   c. Habitual Fo
   d. Habitual SPL

III. Electroglottography

IV. Tape recording
   Pitch perturbation
   Amplitude perturbation
   S/N ratio
   LTAS
   Inverse filter acoustic
   VOT
   Perceptual evaluation

V. Laryngeal mirror
Fibroscopy of larynx
Microscopy of larynx

VI. X-ray laryngography

VII. Vital capacity
Rib cage and abdominal movements

VIII. Audiometry.

To study the vibratory pattern of the vocal folds the methods recommended are stroboscopy, ultra high speed photography, glottography and acoustic analysis.

Acoustic Analysis of Voice :

The acoustic analysis of voice quantifies the parameters which determine the acoustic characteristics of the sound generated. It has been considered vital in the diagnosis and management of patients with voice disorders.

Hirano (1981) has pointed out that the acoustic analysis of voice signal may be one of the most attractive methods for assessing phonatory function or laryngeal pathology because it is non-invasive and provides objective and quantitative data. Many acoustic parameters derived by various methods have been reported to be useful in differentiating between pathological voice and normal voice.

Since any single acoustic parameter is not sufficient to demonstrate the entire spectrum of vocal function or of laryngeal pathology, multi-dimensional analysis using multiple acoustic parameters was attempted by Davis (1976). He used parameters as pitch perturbation quotient, amplitude perturbation quotient pitch amplitude, co-efficient of excess, spectral flatness of the inverse filter spectrum and spectral flatness of the residue signal spectrum to differentiate pathological voices from normal voices.

At present, various computer based methods are being evolved to extract different parameters of voice. These methods are being used mostly in clinical and research work because they are time saving and parameters can be automatically analyzed. Multi-dimensional voice program (MDVP) model 4305 is one such program.

Hirano (1981) has pointed out that it is necessary to use as many parameters of voice as possible in assessing voice and its disorders. Before using the acoustic paramters for the study on vocal stress it is essential to review the usefulness and effectiveness of these paramters in the assessment, diagnosis and treatment of voice and its disorders.

Fundamental frequency:

Voice, the underlying basis of speech, has three major attributes, namely, pitch, loudness and quality.

Pitch is the psychophysical correlates of frequency. Although pitch is often defined in terms of puretones it is clear that noises and other aperiodic sounds, have more or less definite pitches. The pitch of complex tones according to Stevens and Davis (1935) depends upon the frequency of its dominent component, that is, the fundamental frequency in a complex tone. Plomp (1967) states that even in a complex tone, where the fundamental frequency is absent or weak, the ear is capable of perceiving the fundamental frequency based on periodicity of pitch. Emrickson (1959) is of the opinion that the vocal cords are the ultimate determiner of the pitch and that the same general structure of the cords seem to determine the range of frequencies that are produced.

The factors determining the frequency of vibration of any vibrator are mass, length and tension of the vibrator. Thus, mass, length and tension of the vocal cords determine the fundamental frequency of voice.

"... both quality and loudness of voice are mainly dependent upon the frequency of vibration. Hence, it seems apparent that frequency is an important parameter of voice" [Anderson, 1961].

There are various objective methods to evaluate the fundamental frequency of the vocal cords. Stroboscopic procedure, high speed anematagraphy, electroglottography, ultrasonic recordings, strotoscopic, laminography (STROL), Cepstrum pitch detection, digipitch, the 3 M plastiform magnetic tape receiver. Spectrography, pitch computer, the high resolution signal analyser frequency meter, visipitch, vocal-II, computer with speech interface unit and software, etc.

There are changes in fundamental frequency of voice with age.

Beginning with the first year, Fo decrease sharply until about thre years of age, when it makes a gradual decline, reaching the onset of puberty of 11 or 12 years of age. A sex difference is apparent by the age 18 years, which marks the beginning of a substantial drop for male voices, the well known adolescent voice change in the case of females, the decrement in F_o from infancy to adulthood among females is some what inexcess of an octave where as male exhibit an overall decrease approaching two octaves [Kent, 1976].

Studies on Indian population have shown that, in males, the lowering in the fundamental frequency is gradual till the age of 10 years, after which, there is a sudden marked lowering in the fundamental frequencies, which attributable to the changes in vocal apparatus of puberty. In case of females a gradual lowering of F_o is seen [George, 1973; Usha, 1979; Gopal, 1986; Kushal Raj, 1983; Rashmi, 1985].

The study of fundamental frequency has important clinical implications. Cooper (1974) has used spectrographic analysis, as a clinical tool to describe and compare the F_o and hoarseness in dysphonic pattern to before and after vocal rehabilitation. Jayaram (1973) found a significant difference in habitual frequency measure between normals and dysphonics.

A study was conducted by Asthana (1977) to find the effect of frequency and intensity variation on the degree of nasality in cleft palate speakers. The result of the study showed that the cleft palate speakers have significantly less nasality at higher pitch levels than the habitual pitch. But the degree of perceived nasality did not change significantly when habitual pitch was lowered.

Fundamental frequency in speech for normal Indian population (based on studies conducted at AIISH).

Age group in years	Normal fundamental frequency in Hz	
	Males	Females
4-7	233	248
7-11	255	238
11-13	247	240
14-15	177	244
16-25	139	224
26-35	142	230
36-45	147	243
46-55	148	258
56-65	150	235

Most of the therapies of voice disorders are based on the assumption that each individual has an optimum pitch at which the voices will be of a good quality and will have maximum intensity with least expensive of energy [Nataraja and Jayaram, 1982]. Most of the therapies aim to alter the habitual pitch level of the patients or make the patient to use his optimum pitch [Cowan, 1936; West et al., 1957; Anderson, 1961].

It is therefore apparent that the measurement of the fundamental frequency of voice has important applications in both the diagnosis and treatment of voice disorders and also reflects the neuromuscular development in children [Kent, 1976]. Also measurement of F_o is necessary to know the psychological state of an individual.

Frequency ranges in phonation and speech :

Humans are capable of producing a wide variety of acoustic signals. The patterned variations of pitch over linguistic units of differing length (syllables, words, phrases) yield the critical prosodic features, namely intonation [Freeman, 1982].

Variations in fundamental frequency and the extent of range used also relate to the intent of the speaker [Fairbanks and Pronbrast, 1939]. More specifically, the spread of frequency range used corresponds to the mood of the speaker, that is, as Skinner (1935) reports, cheerful animated speech exhibits greater range use than serious throughout speech.

As far as variability of fundamental frequency is concerned, the most extensive study is that of Eguchi and Hirsh (1969), who collected data for 84 years subjects representing adulthood and the age levels of 3-13 years, of one yera intervals, for the vowels |a|, |i|, |u|, as produced in the sentence context. The variability of fundamental frequencies progressively decreased with the age until a maximum was reached at about 10-11 years. This is taken as an index of the accuracy of the laryngeal adjustments during vowel production then the accuracy of control improves continuously over a period of at least 7-9 years.

Hudson and Holbrook (1981) studied the fundamental vocal frequency range in reading, in a group of young black adults, age ranging from 18 to 29 years. Their results indicated a mean range from 81.95 to 158.50 Hz in males and from 139.05 to 266.10 Hz in females. Compared to a similar white population studied by Fitch and Holbrook (1970), the black population has greater mean frequency ranges. Fitches (1970) white, subjects showed a greater range below the mean mode than about. This behaviour was reversed for the black subjects. Hudson (1981) pointed out that such patterns of vocal behaviour may be important clues which alert the listener to the speaker's racial identity.

General conclusions about the diagnostic value of fundamental frequency variability are difficult to make because such measurements are helpful in certain pathological conditions but not in other's [Kent, 1976].

During speech, using a normal phonatory, mechanism a certain degree of variability in frequency is expected and indeed is necessary. Too limited or two wide variations in frequency is an indication of abnormal functioning of the vocal system. However, even if an individual has frequency range within normal limits he may still use little inflection during speech. An octave and a half in males and two octaves in females is considered normal frequency range.

Frequency range in phonation and speech in normals and dysphonics (based on studies conducted at AIISH).

Frequency range in Hz	Normal		Dysphonics	
	Mean	Range	Mean	Range
Phonation	9.00	1-29	210	117-470
Spech	295	117-427	332	121-496

[Nataraja and Savithri, 1990].

Murray and Doherty (1980) reported that the variability in fundamental frequency in speech, along the directional and magnitudinal perturbation factors, enhanced the ability to discrimiante between talkers with no laryngeal known vocal pathology and talkers with cancer of the larynx.

Adams (1955) discovered that stutterers and non-stutterers used a greater range of fundamental frequency while reading at a higher than normal pitch as when compared with reading in their habitual pitch. Moreover, reading in a lower than normal pitch produced less fundamental frequency variability then reading at habitual pitch levels.

Nataraja (1986) found that the frequency range did not change much with age, ie., in the age range of 16-45 years. He also found that females showed a greater frequency range than males in both phonation and speech. Gopal (1986) from a study of normal males from 16-45 years, reported slightly lower frequency range in speech.

Thus review indicates, that it is important to have extensive data on the pitch variations, before it can be applied to the clinical population.

Hanson, Gerraff and Ward (1983), suggested that majority of phonatoiy dysfunctions are associated with abnormal and irregular vibrations of the vocal folds. These irregular vibrations lead to the generation of random acoustic energy, i.e., noise, fundamental frequency and intensity variations. This random energy and aperiodicity of F_o is perceived by human eras as hoarseness. Hence, the spectral, intensity and F_o parameters are more appropriate in quantifying phonatoiy dysfunctions. The frequency related parameters are the most rugged and sensitive in detecting anatomical and physiological changes in the larynx [Hanson, Layerratt and Ward, 1983].

Measurement of F_o variation :

Cycle to cycle variation in fundamental frequency is called pitch perturbation or jitter. Presence of small amount of perturbation in normal voice has been known [Moore, Von Leden, 1958\, Von Leden et al., I960]. Aperiodic laryngeal vibratory pattern have been related to the abnormal voice [Carhart, 1983, 1941;Bolwer, 1964].

Baer (1980) explains vocal jitter as inherent to the method of muscle excitation based on the neuromuscular model of the fundamental frequency and muscle physiology. He has tested the model using EMG from Cricothyroid muscle and voice signals, and claims neuromuscular activities as the major contributor for the occurrence of perturbation.

Wyke (1969), Sorenson, Horii and Leonard (1980) have reported the possible role of laryngeal mucosal reflex mechanism in F_o perturbation. This view of possible role of laryngeal mucosal reflex findings get support from the studies where deprivation or reduction of different information from the larynx occured by anaesthesising the laryngeal muscles. This might have reduced the laryngeal mucosal reflex [Wyke, 1967, 1969] and in turn increase the jitter size on sustained phoonation [Sorenson et al., 1990].

Heiberger and Horii (1982) also says that the mucosal reception in the larynx are important in maintaining the laryngeal tension particularly in sustaining high frequency tone. They stated that "the physiological interpretation of jitter in sustained phonation should probably include both physical and structural variations and myoneurological variations during phonation.

A number of high speed laryngoscopic motion pictures reveal that the laryngeal structures (the vocal folds) were not totally symmetric. Different amounts of mucous accumulates on the surface of the vocal folds during vibration. In addition turbulent air flow at the glottis also causes some perturbation. Limitations of laryngeal servo mechanism through the articular mucosal relfex system [Gould and Okamura, 1974; Wyke, 1967] may also introduce small perturbation in laryngeal muscle tone. Even without considerationof reflex mechanism, the laryngeal muscle tone have inherent perturbation due to the time straggered activities which exist in any voluntary muscle contractions.

Von Leden et al. (1960) reported that the most frequent observation in the pathological conditions is that there is a strong tendency for frequent and rapid changes in the regularity of vibratory pattern. The variations in the vibratory pattern are accompanied by transient pressure changes across the glottis which are reflected acoustically in disturbance of the fundamental frequency and amplitude patterns. Hence, pitch perturbation and amplitude perturbation values are greater in pathological conditions.

Wilcox (1978), Wilcox and Horii (1980) reported that a greater magnitude of jitter occurs with advancing age which they attributed to the reduced sensory contribution from laryngeal mechanoreceptors. However, these changes in voice with age may also be due to physical changes associated with respiratory and articulatory mechanism. These perturbations and related parameters in pitch and amplitude can be measured. There are different algorithms for the measurements of pitch perturbations. Some of them are :

1. Absolute jitter/sec/or jita :

$$\text{Jita} = \frac{1}{N-1} \sum_{i=1}^{N-1} T_0^{(i)} - T_0^{(i-1)}$$

Where

$T_0^{(i-1)}$ i = 1,2, ... , N extractedpitch period data
,N = PER, Number of extracted pitch periods.

2. Jitter per unit or jitt:

$$\text{Jitt} = \frac{\frac{1}{N-1} \sum_{i=1}^{N-1} T_0^{(i)} - T_0^{(i-1)}}{\frac{1}{N} \sum_{i=1}^{N} T_0^{(i)}}$$

Where

$T_0^{(i)}$, i = 1,2, . . . , N extractedpitch period data
N = PER, Number of extracted pitch periods.

3. Pitch period perturbation quotient (%) :

$$PEQ = \frac{\frac{1}{N-4}\mathop{\varepsilon}\limits_{i-1}^{N-4} \Big/ \frac{1}{5}\mathop{\varepsilon}\limits_{r=0}^{4} T_0^{(i+r)} - T_0^{(i+2)}}{\frac{1}{N}\mathop{\varepsilon}\limits_{i-1}^{N} T_0^{(i)}}$$

Where

$T_0^{(i)}$, $i = 1, 2, \ldots, N$ extracted pitch period data
N = PER, Number of extracted pitch periods.

4. Smoothed pitch period perturbation quotient (%)

$$PPQ = \frac{\frac{1}{N-SF+1}\mathop{\varepsilon}\limits_{i-1}^{N-SF+1} \Big/ \frac{1}{SF}\mathop{\varepsilon}\limits_{r=0}^{SF-1} T_0^{(i+r)} - T_0^{(i+m)}}{\frac{1}{N}\mathop{\varepsilon}\limits_{i=1}^{N} T_0^{(i)}}$$

$T_0^{(i)}$, $i = 1, 2, \ldots, N$ extractedpitch period data
N = PER, Number of extracted pitch periods.

SF = Smoothing factor

5. Co-efficient of F_0 variation (%)

$$VFO = \frac{\frac{}{F_0}\sqrt{\frac{1}{N}\mathop{\varepsilon}\limits_{i=1}^{N} \Big/ \frac{1}{N}\mathop{\varepsilon}\limits_{i=1}^{N} F_0^{(i)} - F_0^{(i)^2}}}{\frac{1}{N}\mathop{\varepsilon}\limits_{i=1}^{N} F_0^{(i)}}$$

Where,

$$F_0 \frac{1}{N}\mathop{\varepsilon}\limits_{i=1}^{N} F_0^{(i)}, \text{ and}$$

$$F_0^{(i)} = \frac{1}{T_0^{(i)}} - \text{ Period to period } F_0 \text{ values}$$

$T_0^{(i)}$, $i = 1, 2, \ldots, N$ extracted pitch period data
N = PER, Number of extracted pitch periods.

6. Relative average perturbation (%)

$$RAP = \frac{\frac{1}{N-2} \underset{i-2}{\overset{N-1}{\varepsilon}} \Big/ \overline{T_0^{(i-1)} + T_0^{(i)} + T_0^{(i+1)}}}{\frac{1}{N} \underset{i=1}{\overset{N}{\varepsilon}} T_0^{(i)}} - T_0^{(i)}$$

Where

$T_0^{(i)}$, $i = 1,2, \ldots, N$ extracted pitch period data
N = PER, Number of extracted pitch periods.

Liberman (1963) found that pitch perturbations in normal voice never exceeds 5 m sees in the steady state portion of sustained vowels. Similar variations in fundamental periodicity of the acoustic wave form have been measured by Fairbanks (1942).

Iwata and Vonledon (1970) reported that the 95% confidence limits of pitch perturbations in normal subjects ranged from -0.19 to +0.2 msec.

Several factors have been found to effect the values of jitter such as age, sex, vowel produced, frequency and intensities.

Higgins and Saxman (1989) reported higher value of frequency perturbation in males than females. Gender difference may exist not only in magnitude, but also in the variability of frequency perturbation.

Sorrenson and Horii (1984) reported that normal female speakers have more jitter than normal male speakers. This result contradicts the findings of Higgins and Saxman, (1989).

Robert and Baken, (1989) reported higher jitter values in males and females. They attributed this difference to F_o. When the F_o increases the percentage of jitter values decreases.

Zemlin, (1962) has reported greater jitter values for |a| than |i| and |u| showed lowest value. This must be supported by the studies of Wilcox (1978) and Linville and Korabic (1987).

Johnson and Michel. (1969) reported greater jitter value for high vowels than low vowels in 12 English |y| vowels.

Wilcox and Horii, (1980) reported that |u| was associated with significantly smaller jitter (0.55%) than |a| and |i| (0.68% and 0.69% respectively).

Sorrensen and Horii, (1984) studied the vocal jitter during sustained phonation of |a|, |i| and |u| vowels. The result showed that jitter values were low for ja| with 0.71%, high for |i| with 0.96% and intermediate for |u| with -0.86%.

Linville and Korabic, (1987) have found that intraspeaker variability tend to be greatest on the low vowel |a|, with less variability on high vowels |i| and |u.

The values of the measures of jitter are dependent upon the vowels produced during sustained phonation and also the frequency and intensity level of the phonatory sample, the type of phonatory initiation, and also to the level of stress.

Ramig (1980) postulated that jitter values should increase when subjects are asked to phonate at a specific intensity, and/or as long as possible.

Measurement of variation in intensity :

Cycle to cycle variation of amplitude is called intensity peiturbation or shimmer. These perturbations in amplitude can be measured using several parameters. There are different algorithms for measurement of amplitude perturbations. Some of them are given below:

1. Shimmer in dB/dB/or sh dB :

$$\text{sh dB} = \frac{1}{N-1} \mathop{\varepsilon}_{i-1}^{N-1} 20 \log(A^{(i+1)} / A^{(i)})$$

Where

$A^{(i)}$, i = 1,2, . . . , N extracted peak to peak amplitude data.
N = Number of extracted impulses.

2. Shimmer percent (%) or shim :

$$\text{Shim} = \frac{\frac{1}{N-1}\sum_{i=1}^{N-1} A^{(i)} - A^{(i+1)}}{\frac{1}{N}\sum_{i=1}^{N} A^{(i)}}$$

Where

$A^{(i)}$, i = 1,2, . . . , N extracted peak to peak amplitude data.
N = Number of extracted impulses.

3. Amplitude perturbation quotient |%| - APQ :

$$\text{SAPQ} = \frac{\frac{1}{N-4}\sum_{i=1}^{N-4} \Big/ \frac{1}{5}\sum_{4=01}^{4} A^{(i+r)} - A^{(i+2)}}{\frac{1}{N}\sum_{i=1}^{N} A^{(i)}}$$

$A^{(i)}$, i = 1,2, . . . , N extracted peak to peak amplitude dat.a
N = Number of extracted impulses.

4. Smoothed amplitude perturbation quotient (SAPQ) :

$$\text{SAPQ} = \frac{\frac{1}{N-sf+1}\sum_{i=1}^{N-sf+1} \Big/ \frac{1}{sf}\sum_{r=0}^{sf-1} A^{(i+r)} - A^{(i+m)}}{\frac{1}{N}\sum_{i=1}^{N} A^{(i)}}$$

Where,

$A^{(i)}$, i = 1,2, . . . , N extracted peak to peak amplitude data.
N = Number of extracted impulses.
SF = Smoothing factor

5. Co-efficient of amplitude variation (%) VAM:

$$\text{SAFQ} = \frac{\frac{1}{N}\sum_{i=1}^{N} \Big/ \frac{1}{N}\sum_{j=1}^{N} A^{(j)} - A^{(i)2} \Big/}{\frac{1}{N}\sum_{i=1}^{N} A^{(i)}}$$

Where,

$A^{(i)}$, i = 1,2, . . . , N extracted peak to peak amplitude data.
N = Number of extracted impulses.

Shimmer in any given voice is dependent atleast upon the modal frequency level, the total frequency range and the SPL relative to each individual voice.

Micheal and Wendahl (1971) and Ramig (1980) postulated that Shimmer values should increases when subjects are asked to phonate at a specific intensity and/or as long as possible.

Vowel produced and sex are the two factors affecting shimmer values as reported in the literature. Sorenson and Horii (1983) reported that normal female speakers have less shimmer than normal male speakers. Wilcox and Horii (1980), reported that shimmer values are different for different vowels. Sorensen and Horii (1983) studied the vocal shimmer during the sustained phonation of |a|, |i| and |u| vowels. The results showed that shimmer values was lowest for |u| with 0.19 dB, highest for |a| with 0.33 dB and intermediate for |i| with 0.23 dB. This results is supported by Horii (1980).

Several investigators have studied the measures of amplitude perturbation in normals and pathological groups. Vanaja (1986), Tharmar (1991) and Suresh (1991) have reported that as the age increased there was increase in fluctuations in frequency and intensity of phonation and this difference was more marked in females. Nataraja (1986) has found that speed of fluctuation in fundamental frequency and extent of fluctuation in intensity parameters were sufficient to differentiate the dysphonics from the normals.

Higgins and Saxman (1989) investigated within subject variation of three vocal frequency perturbation indices over multiple sessions for 15 female and 5 male young adults (pitch perturbation quotient and directional perturbation factor). Co-efficient of variation for pitch perturbation quotient and directional perturbation factor were considered indicative of temporal stability of these measures. While jitter factor and pitch perturbation quotient provided redundant information about laryngeal behaviour. Also jitter factor and pitch perturbation quotient varied considerably within the individual

Yamagihara (1967) states that in cases with slight degree of perceived hoarseness, the noise component appears in the format region and in severe hoarseness, additional noise over 3 kHz can be noticed.

On sound spectrographic analysis Yanagihara (1967)has found that the sustained vowels perceived as hoarse has the following characteristics.

1. Noise components in the main formats of various vowels.
2. High frequency noise component.
3. Loss of high frequency harmonic component.

As the degree of judged hoarseness increases more noise appears and replaces the harmonic structure. He also developed a technique for visually evaluating hoarseness based on the spectrogram.

Emanuel et al (1979) estimated noise levels in the spectra of sustained vowels and found a relationship between the spectral noise level (SNL) and the perceived magnitude of the roughness of the voice, they did not consider the level of harmonic component of the spectrum.

Yumoto, (1982) developed harmonic to noise ratio (H/N) as an objective and quantitative evaluation of the degree of hoarseness. The result showed a higher significant agreement between H/N calculation and subjective evaluation of the spectrograms. H/N ratio proved useful in quantitative assessment of results of treatment of hoarseness.

Yumoto, (1982) and Yumoto, et.al, (1983) have also discussed the importance of both the cycle-to-cycle periodicity and the wave form within one pitch period for the evaluation of hoarseness. Objective evaluation of normals and hoarse voices was performed considering that the hoarse voices was performed considering that the hoarse voices shows a prominent F_o intensity compared with harmonics in the voice spectrum. The relative harmonic intensity (Hr) obtained from a stable position of the sustained vowels |a|, is defined as the intensity of the second and higher harmonics expressed as percentage of the total vocal intensity. 95% of the normal voices examined have relative harmonic intensity larger than the critical value of 67.2%, whereas 90% of the hoarse voices have relative harmonic intensity smaller than the critical value. The harmonic intensity analysis thus provides good discrimination between normal and hoarse voices.

Kasuya, Ogawa, Mashima and Ebihara (1984) devised an adaptive comb filtering method operating in the frequency domain to estimate noise components from a sustained vowel phonation and proposed an acoustic measures of the amount of noise in the pathologic voice signal for the purpose of applying it in the screening of laryngeal disease by voice.

Higgins and Saxman (1989) investigated within subject variations of three vocal frequency perturbation indices over multiple sessions for 15 female and 15 male young adults (pitch perturbation quotient and directional perturbation quotient). Co-efficient of variation for pitch perturbation quotient and directional perturbation factor was considered indicative of temporal stability of these measures. Jitter factor and pitch perturbation quotient provided redundant information about laryngeal behaviour. Also jitter factor and pitch perturbation quotient varied considerably with the individual across sessions while directional perturbation a more temporarily stable measure.

Venkatesh, (1992), reported jitter ratio, relative average perturbation, 3 point (RAP3), deviation from linear trend (DLT), shimmer in dB (ShdB) and amplitude perturbation quotient (APQ) to be most effective parameters in differentiating between normal males, normal females and dysphonic groups. They added that in the clinical application, shimmer in dB is most effective and can act as a quick screening device, and in pitch perturbation measures like jitter ratio, RAP (3 point) and DLT are most useful in differentiating laryngeal disorders.

Quality of voice have been defined as the hearer's impression of the complex sound wave, its harmonic and inharmonic partials and the relative intensity, number and duration of these components. Therefore, the study of spectra is essential to understand the basis of different types of qualities - normal and abnormal.

A number of spectral analyzers are available for analysis of speech and noise. Experiments with voice samples show that normalized noise energy is especially effective for detecting glottic cancer, recurrent laryngeal paralysis and vocal nodules. But 22.6% of patients with glottic -T1 are incorrectly classified as normal. However, normalized noise energy has shown effective in discriminating glottic T_3 - T_4. The detect ability of other laryngeal diseases can be improved by incorporating other measures -jitter and shimmer [Kasayu et al., 1984].

Thus, the review of literature regarding acoustic parameters show that these have been found to be useful to study the normal and abnormal functioning of voice. However, there are very few studies reporting the use of acoustic parameters in exploring the changes in voice due to stress. Very little is known about changes due induced stress by means of cognitive workload tasks.

The present study is designed with the aim to:

a) Study vocal parameters in normal subjects and investigate the acoustic correlates of cognitively induced stress in them.
b) Highlight the sensitive acoustic parameters for measurement of stress.

METHODOLOGY

The main aim of this study is to differentiate the effects of psychological stress from the effects of the cognitive workload task. For this, an experiment was planned. In this, the subjects would perform the cognitive workload tasks in a stressful experimental environment.

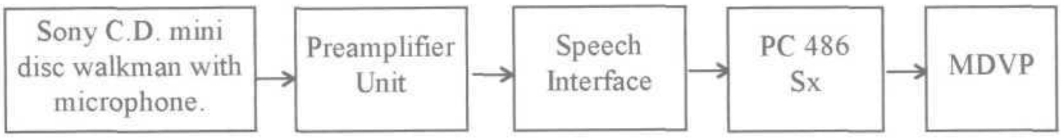
The stimulus for cognitive workload tasks i.e., the commonly used English words and tongue twisters were selected based on the responses of 10 English speaking adults and then randomised to avoid any bias. A list of 10 tongue twisters and 15 English words was given to 10 English speaking normal adult subjects, the subjects were asked to rate each word and tongue twister on a 5 point rating scale (0-most commonly used, 5-unknown). The English word and tongue twister receiving maximum most favourable response were chosen i.e., "speech" and 'she sells sea shells on the sea shore' respectively.

Subjects :

Twenty university students (10 males and 10 females), between 17 and 22 years who were exhibiting nonnal hearing and voice, participated in this study. The experiment is carried out during the first few months of their academic year, so that the subjects are not aware of the speech variations under stress conditions.

Instrumentation :

The speech samples are recorded on a Sony CD many disk walkman with digital audio tape (DDS-90, 3M, 4mm, data tape) with microphone placed at 4 - 6 inches from the subject's mouth. VAGHMI software programme is used for the subjects to hear his or her voice delayed. All recording took place in the Speech Sciences Laboratory of All India Institute of Speech and Hearing, Mysore. The speech samples are then introduced through a cable to MDVP (Multi-dimensional voice program), optional software of the CSL (computer speech laboratory), and then analysed.



DATA ACQUISITION AND FLOW CHART

Enter MDVP
Connect microphone or other inputs to external module.

|

Adjust input level on CSL external module to avoid overloading. If using microphone, turn off speaker volume or select capture on the main menu and then "'set' for sustained phonation.

|

Initiate acquisition process using pull-down menu or by pressing the Fl key for single channel capturing.

|

Immediately after desired signal is recorded, press any key to stop recording.

|

Press the F7 key for analysis of the captured signal. After analysis is over press the F8 key for display of values of the parameters and F9 key for the grapahical display.

Procedure :

Different stresses are employed to induce psychological stress. Each subject is given instructions in which it is explained that he or she has to perform the task as rapidly as possible without errors and that any errors committed in the different tasks will reduce his or her final grade in the course. The instructions are given only once and the subjects has to concentrate and understand. It is also explained that during the task, the experimenter will raise her finger and that it is necessary to prolong the vowels |a|, |i|, |u| respectively during the time the finger is raised. The tasks corresponding to the four conditions (baseline and three experimental conditions) are the following :

1) **Baseline** : Each subject is asked to spell the English word "speech". After the pronounciation of alphabet 'E', in the word the subject is asked to prolong vowel |a|, followed by |i|, and ju| respectively, for 5 - 6 seconds each. The subject can then continue with the spelling.

2} **Experimental condition I:** Each subject is asked to read the given tongue twister "she sells sea shells on the sea shore'. After reading the word "shells" the subject is asked to prolong vowel |a|, followed by |i| and |u respectively, for 5 - 6 seconds each. The subject can then continue with reading the tongue twister.

3} **Experimental Condition II** : Each subject is given to read the same tongue twister as above, but with the delayed auditory feedback (DAF). Delay interval of 250 msec, for males and 200 msec for females is selected. The subjects are asked to prolong the vowels |a|, |i|, |u| for 5 - 6 seconds after reading the word "Shells". The subjects can then continue reading the tongue twister with DAF.

4) **Experimental Condition III** : The subject is asked to spell the English word "speech" in reverse order. After the pronounciation of alphabet "E' in the word, the subject is asked to prolong vowel |a|, followed by |i| and |u| for 5 - 6 seconds each. The subject can then continue with the reverse spelling.

The voice samples for phonation are analysed with the help of the MDVP software. After the anlysis the display of the results is obtained for each trial of each vowels for all subjects, separately for males and females. Further data was submitted to statistical analysis using SPSS software to obtain descriptive as well as the non-paramatric statistical [Wilcoxn's Sign Ranked Test] information.

As a part of the study, as suggested by Lively, et.al, an experiment is undertaken to find out whether the change in voice is due to stress-loaded instructions or the tasks of cognitive workload. The same subjects performed the same experimental tasks in the same order of presentation but without the stress-loaded instructions. The recorded samples are then subjected to the statistical analysis.

The following acoustic parameters from MDVP are considered for analysis :

1. Average fundamental frequency (Fo)
2. Average pitch period (To)
3. Highest fundamental frequency (Fhi)
4. Lowest fundamental frequency (Flo)
5. Standard deviation of fundamental frequency (STD)
6. Fo tremor frequency (Fftr)
7. Amplitude tremor frequency (Fatr)
8. Absolute jitter (jita)
9. Jitter percent (Jitt)
10. Relative average perturbation (RAP)
11. Pitch period perturbation quotient (PPQ)
12. Smoothed pitch period perturbation quotient (SPPQ)
13. Co-efficient of fundamental frequency variation (Vfo)
14. Shimmer in dB (shdB)
15. Shimmer in percent (shim)
16. Amplitude perturbation quotient (APQ)
17. Smoothed amplitude perturbation quotient (SAPQ)
18. Co-efficient of amplitude variation (Vam)
19. Noise to harmonic ration (NHR)
20. Voice turbulence index (VTI)
21. Soft phonation index (SPI)

22. Frequency tremor intensity index (FTRI)
23. Amplitude tremor intensity index (ATRI)
24. Degree of voice breaks (DVB)
25. Degree of sub-harmonic breaks (DSH)
26. Degree of voiceless (DUV)
27. Number of voice breaks (NVB)
28. Number of sub-harmonic segments (NSH)
29. Number of unvoiced segments (NUV).

The definitions for each of these parameters are given in Appendix.

RESULTS AND DISCUSSION

The objective of the present study was to investigate the acoustic correlates of cognitively induced stress in terms of vocal parameters in normal subjects. Study was also designed to identify the acoustic parameters which were sensitive to the stress, using multidimensional voice profile software (Kay Elementrics Inc. New Jersey: MDVP). The following experiment was carried out for this purpose.

In the experiment, subjects performed cognitive workload tasks under a stressful condition, performing the tasks as rapidly as possible without errors and with the knowledge that any errors committed would reduce their grade in a course.

Four testing conditions were used for this purpose.-

1) Baseline measurement in which subjects spelled the English word.
2) Reading of the tongue twister task
3) Reading of the tongue twister with delayed auditory feedback.
4) Spelling the English word in reverse order.

In each condition the subjects prolonged the vowels /a/, /i/, */u/* for approximately for 5 seconds.

The results of the experiment in all the four conditions, with reference to each parameter are as follows:

1. Average fundamental frequency (Fo):

Average fundamental frequency was measured during phonation of/a/, /i/, *lul* using MDVP software. The mean, SD and range for average Fo are presented in table I for both male and female subjects in the baseline and the three experimental conditions.

The Z- values given are obtained by comparing the measures of three experimental conditions with those of the baseline. These values are given for the experimental conditions and the significant difference with baseline is also indicated.

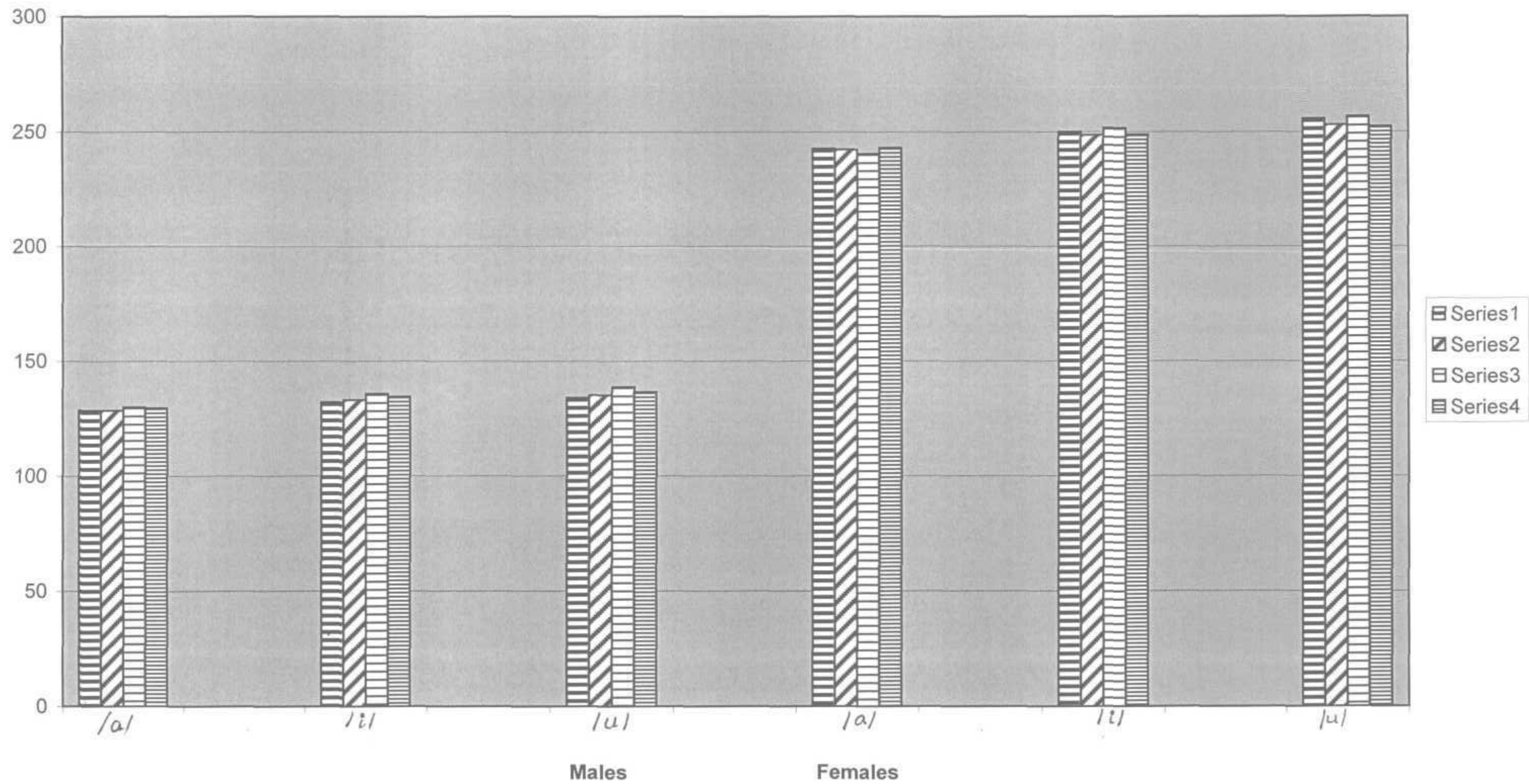
Table -I:- Average fundamental frequency (Fo) values for males and females in the baseline and experimental conditions.

CONDITIONS	*MALES*			*FEMALES*		
	/a/	*/i/*	*/u/*	*/a/*	*/i/*	*/u/l*
1. Baseline Condition						
Mean	128.56	132.06	134.06	242.68	249.89	255.72
SD	18.33	17.75	18.23	22.07	21.28	21.66
Range	59.10	62.55	62.66	64.03	53.49	50.29
2. Experimental Condition I (Tongue Twister Task)						
Mean	128.48	133.02	135.16	242.24	248.46	252.89
SD	15.47	18.57	19.55	21.13	22.45	23.32
Range	55.36	81.07	85.24	55.00	59.01	61.35
Z- value	0.96 (-)	0.57 (-)	0.96 (-)	0.57 (-)	0.33 (-)	0.20 (-)
3. Experimental Condition II (Tongue Twister with DAF Task)						
Mean	129.90	135.70	138.71	240.29	251.62	256.53
SD	16.91	19.54	20.81	15.98	17.24	18.12
Range	64.51	71.16	75.75	50.43	49.76	46.40
Z- value	0.51 (-)	0.39 (-)	0.88 (-)	0.33 (-)	0.57 (-)	0.64 (-)
4. Experimental condition III (Reverse spelling Task)						
Mean	129.51	134.45	136.51	242.98	248.78	252.29
SD	17.22	20.48	21.62	20.87	22.03	22.90
Range	54.86	70.52	75.14	51.92	53.84	55.75
Z- Value	0.64 (-)	0.33 (-)	0.87 (-)	0.79 (-)	0.57 (-)	0.07 (-)

As seen from the table, the mean, SD and Range Values for all the four conditions are within normal limits for both males and females in the baseline condition. Norms as given by Anitha (1994). However, the range is found to be

55a

GRAPH I - Mean Values of Vowles /a/, /i/ & /u/ for males and females of the Average Fundamental Frequency



slightly higher for phonation of /i/ and /u/ by males in the tongue twister and tongue twister with DAF condition. This difference is also not stastistically significant.

Other statistical analysis revealed no significant difference from the baseline condition. The level of significance for female *lul* in the reverse spelling task is found to be 0.07, which is tending towards significant difference between the two conditions. This can be attributed to higher level of stress in this condition. However, this being only one variable that is showing a difference, is not valid.

Thus, though the review of literature reveals an increase in fundamental frequency (Scherer, 1986; Mendoza & Carballo 1998) during stressed condition, no such increase was observed in this study. An increase in fundamental frequency may be the result of higher levels of stress.

2. Average Pitch Period (To):

Average pitch period was measured during phonation of /a/, /i/, */u/* using MDVP software. The mean, SD and range for average pitch period (To) for baseline and the three experimental conditions are given in table II for both male and female subjects.

The table also gives the Z-values which are obtained by comparing the respective measures of the experiemntal conditions with those of the baseline condition for both males and females. Significant difference, if any, is also indicated.

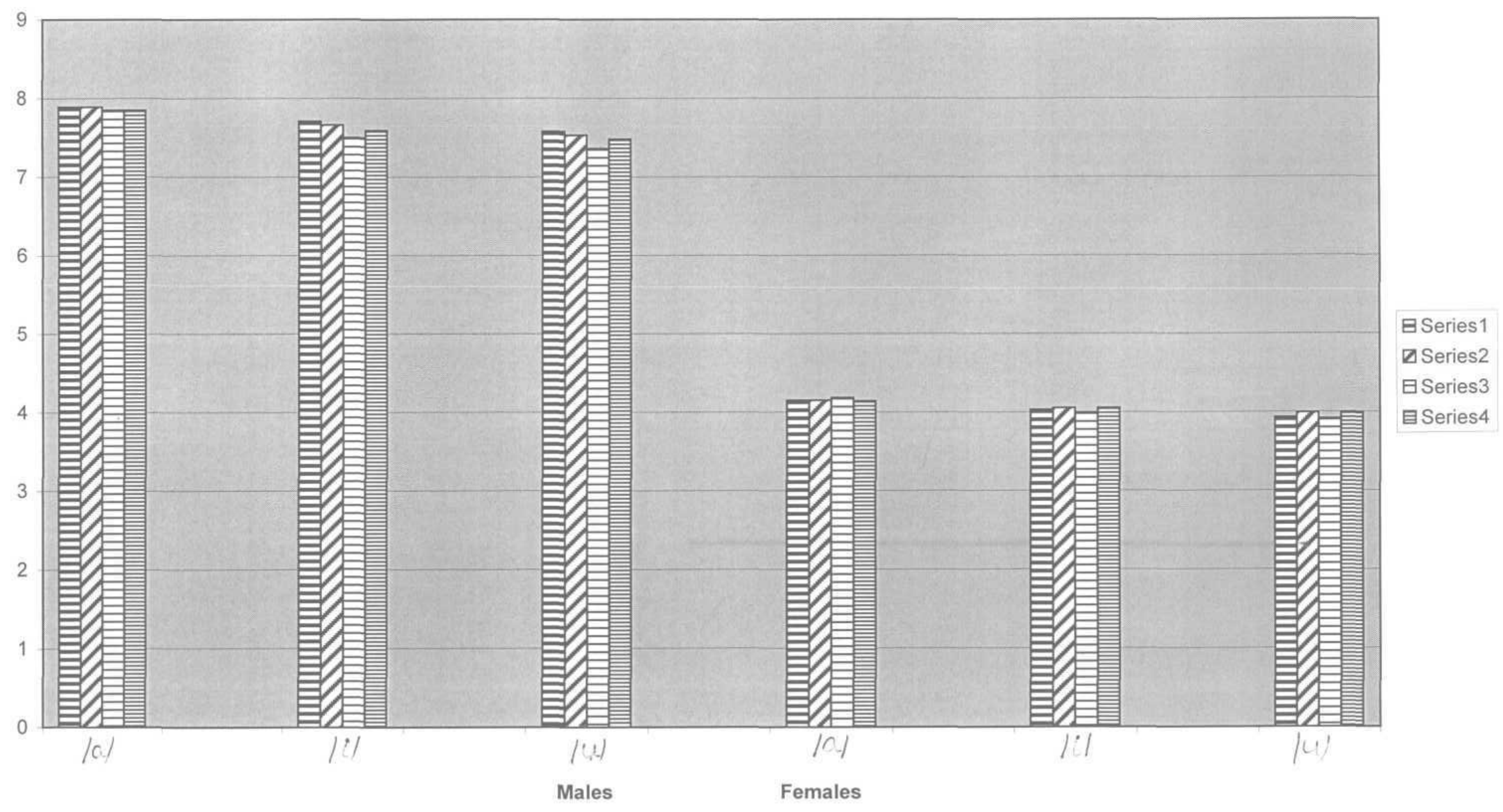
The mean, SD and range values for the baseline condition are similar to the normal values given by Anitha (1994). The mean, SD and range values for the three experiemental conditions are also very similar to those in the baseline condition.

Statistical Analysis revealed no significant difference for any of the three experimental conditions when compared with the baseline condition. Studies by other researchers also report of no change in average pitch period (To) for the stressed conditions.

Table - II:- Average Pitch Period (To) values for males and females in the baseline and experimental conditions.

CONDITIONS	*MALES*			*FEMALES*		
	/a/	**/i/**	**/u/**	/a/	/i/	/u/
1. *Baseline Condition*						
Mean	7.89	7.71	7.58	4.15	4.03	3.93
SD	1.04	1.06	1.00	0.38	0.34	0.33
Range	3.77	3.70	3.43	1.12	0.86	0.78
2. *Experimental Condition I (Tongue Twister Task)*						
Mean	7.89	7.66	7.53	4.15	4.05	3.99
SD	0.99	1.06	1.02	0.36	0.37	0.37
Range	3.59	3.52	3.37	0.92	0.96	0.95
Z- value	0.96 (-)	0.96 (-)	0.96 (-)	0.39 (-)	0.28 (-)	0.11 (-)
3. *Experimental Condition II (Tongue Twister with DAF Task)*						
Mean	7.85	7.50	7.36	4.18	3.99	3.91
SD	1.06	1.04	1.05	0.27	0.27	0.27
Range	4.02	3.82	3.90	0.86	0.80	0.71
Z- value	0.87 (-)	0.20 (-)	0.24 (-)	0.38 (-)	0.57 (-)	0.51 (-)
4. *Experimental condition III (Reverse spelling Task)*						
Mean	7.85	7.59	7.48	4.14	4.05	3.99
SD	1.07	1.14	1.09	0.35	0.36	0.36
Range	3.51	3.95	3.74	0.87	0.87	0.88
Z- Value	0.51 (-)	0.24 (-)	0.38 (-)	0.80 (-)	0.44 (-)	0.11 (-)

GRAPH II - Mean Values of Vowles /a/, /i/ & /u/ for males and females of the Average Pitch Period



3. Highest fundamental frequency (Hfo):-

The highest fundamental frequency (Hfo) was measured during phonation using MDVP software. Table III gives the mean, SD and range for HFo for baseline condition, and the three experimental conditions.

The table also gives the Z-scores when the three experimental conditions were compared with the baseline. Any significant difference is also indicated.

As seen from the table, the mean, SD and range values are within normal limits for the baseline condition, for both males and females. In the first experimental condition i.e. tongue twister task, lower highest fundamental frequency values were observed for phonotion of vowel *I'll* by both males and females, when compared to the baseline condition. Also, the range was higher for phonation of /u/ in the second experimental condition i.e. tongue twister with DAF task. Other values for this condition were within normal limits for both males and females. The mean and SD values were lower in the reverse spelling experimental task.

Statistical Analysis revealed significant difference between the first experiemental and the baseline condition for phonation of *I'll* by males and females (Z for male *I'll* = 0.01, for female *I'll* = 0.05). Also significant difference was observed between baseline and third experimental condition for phonation of /a/ by males (Z=0.02) and *I'll* by females (Z=0.06).

However, these findings are contradictory with Scherer's Model (Scherer, 1986). Higher levels of stress are needed to achieve higher fundamental frequency.

4) Lowest fundamental frequency (Lfo)

It was the lowest fundamental frequency for all extracted pitch periods. Table IV gives the mean, SD and range for Lfo for baseline and three experimental conditions for both males and females.

The table also shows the Z-values which are obtained when the experimental conditions were compared with the baseline condition. Significant difference, if any, is also indicated by +/- sign, referring presence or absence of difference respectively.

The table shows the mean, SD and range values for the baseline and the three experimental conditions to be with in the normal limits. Norms as given by Anitha (1994).

Also, statistical analysis revealed no significant difference between the baseline and the experimental conditions for both males and females.

Thus the acoustic parameter of lower fundamental frequency does not help us to differentiate between the induced stress and the normal condition

Table - III:- Highest fundamental frequency (Hfo) values for males and females in the baseline and experimental conditions.

CONDITIONS	*MALES*			*FEMALES*		
	/a/	/i/	/u/	/a/	/i/	/u/
1. Baseline Condition						
Mean	138.44	*162A9*	147.83	256.49	*216.51*	285.89
SD	22.72	52.62	25.73	31.19	25.99	33.66
Range	84.75	179.96	76.16	97.27	87.95	107.75
2. Experimental Condition I (Tongue Twister Task)						
Mean	135.56	140.17	150.55	265.46	262.46	276.04
SD	16.11	20.17	33.73	48.01	23.36	34.42
Range	56.88	63.95	109.49	67.50	64.09	105.77
Z- value	0.96 (-)	0.01 (-)	0.96 (-)	0.96 (-)	0.05 (-)	0.24 (-)
3. Experimental Condition II (Tongue Twister with DAF Task)						
Mean	140.19	145.28	165.71	248.95	270.85	273.97
SD	22.67	20.33	63.53	18.47	24.09	26.91
Range	72.16	70.22	72.31	56.15	79.63	80.29
Z- value	0.65 (-)	0.58. (-)	0.33 .(-)	0.17 (-)	0.17 (-)	0.17 (-)
4. Experimental condition III (Reverse spelling Task)						
Mean	132.54	140.47	151.86	265.50	263.77	274.34
SD	20.45	22.35	36.10	20.50	23.82	29.06
Range	61.31	76.77	109.94	68.60	57.40	84.86
Z- Value	0.02 (+)	0.95 (-)	0.79 (-)	0.20 (-)	0.06 (+)	0.17 (-)

GRAPH III - Mean Values of Vowles /a/, /i/ & /u/ for males and females of the Highest Fundamental Frequency

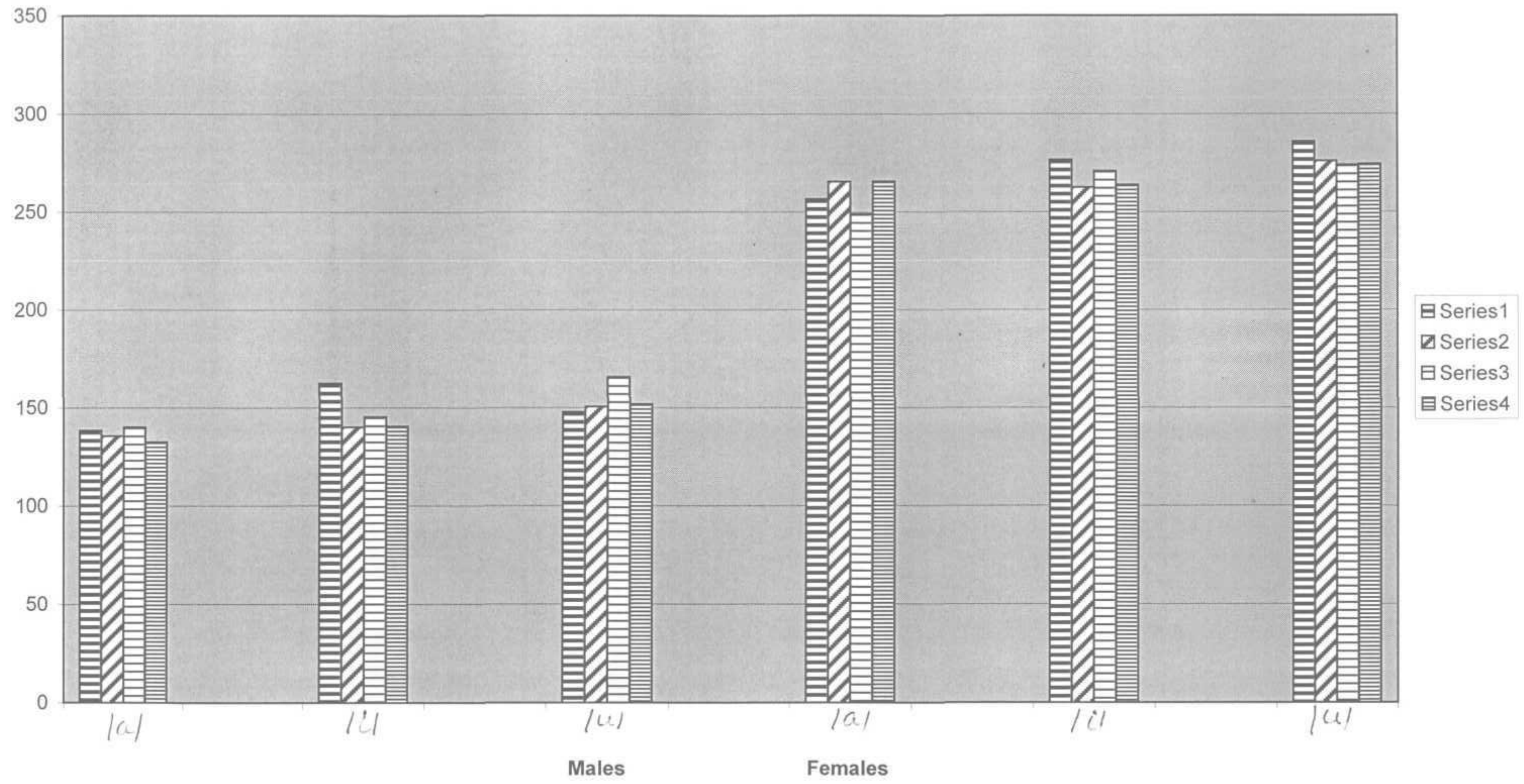
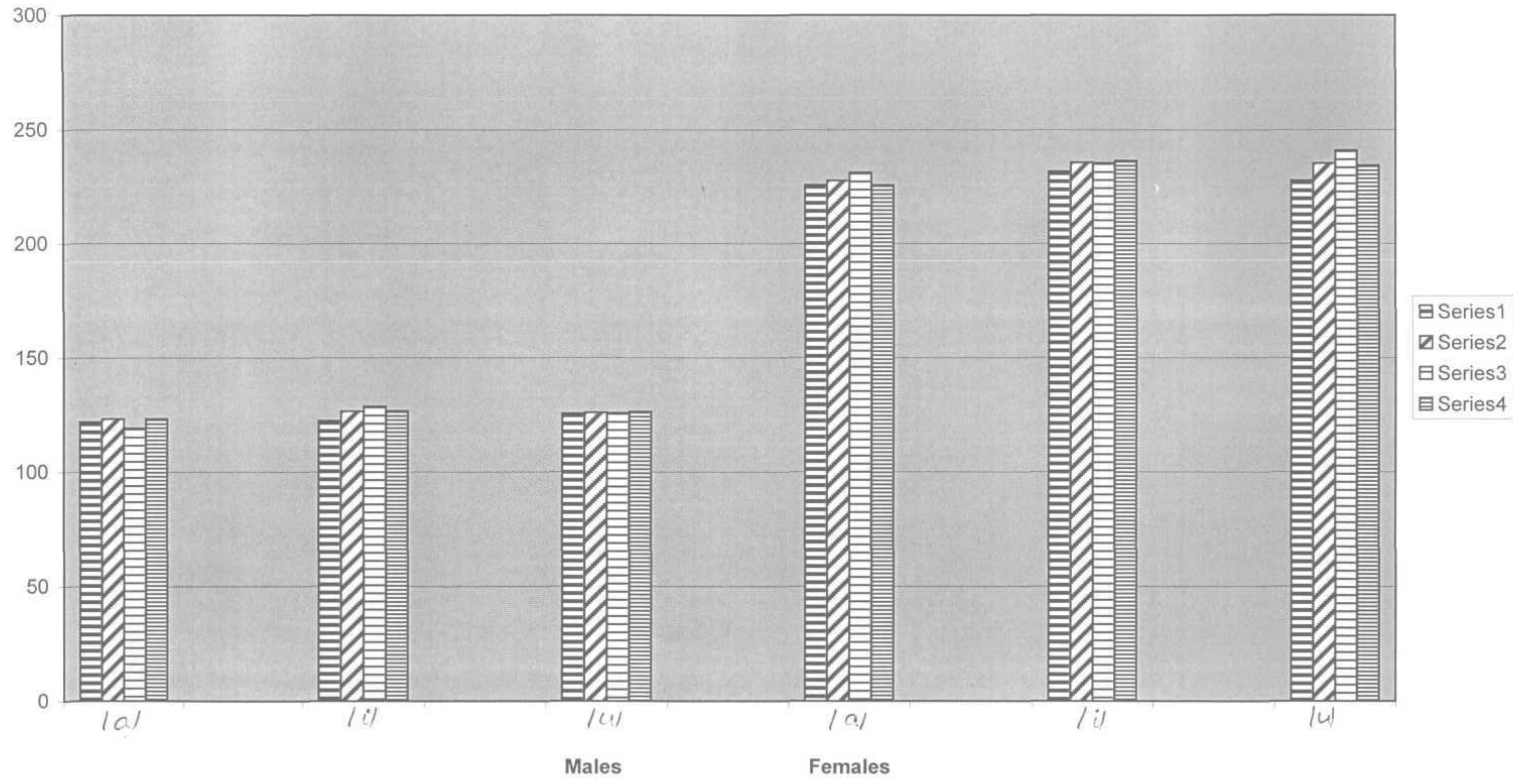


Table - IV :- Lowest fundamental frequency (Lfo) values for males and females in the baseline and experimental conditions.

CONDITIONS	*MALES*			*FEMALES*		
	/a/	/i/	/u/	/a/	/i/	/u/
1. Baseline Condition						
Mean	121.93	122.27	125.55	225.71	231.70	227.79
SD	14.79	19.47	20.37	20.95	25.02	30.09
Range	51.76	59.07	67.05	85.84	84.52	88.25
2. Experimental Condition I (Tongue Twister Task)						
Mean	123.24	126.98	125.92	227.67	235.61	235.28
SD	14.65	17.04	19.04	20.52	20.52	22.51
Range	51.43	55.56	61.77	59.93	55.26	68.87
Z- value	0.79 (-)	0.28 (-)(-)	0.64 (-)	0.44 (-)	0.20. (-)	0.39 (-)
3. Experimental Condition II (Tongue Twister with DAF Task)						
Mean	119.12	128.62	125.72	231.19	235.36	240.93
SD	24.40	20.06	23.78	14.86	16.39	14.34
Range	89.30	72.49	91.03	45.87	44.94	38.52
Z- value	0.95 (-)	0.96 (-)(-)	0.11 (-)	0.28 (-)	0.72	0. 17 (-)
4 Experimental condition III (Reverse spelling Task)						
Mean	123.15	126.67	126.30	225.65	236.36	234.28
SD	15.89	23.36	16.69	24.18	21.53	25.08
Range	63.90	84.87	54.66	74.91	60.89	68.07
Z- Value	0.72 (-)	0.16 (-)	0.33 (-)	0.88 (-)	0.17 (-)	0.96 (-)

GRAPH IV - Mean Values of Vowels /a/, /i/ & /u/ for males and females of the Lowest fundamental frequency



5) Standard Deviation of fundamental frequency (STD):-

STD is the standard deviation of all extracted period to period fundamental frequency values. The mean, SD and range for STD for both males and females for baseline and the three experimental conditions are given in table V.

The table also shows the Z-values and the significant difference if any, between the baseline and the three experimental conditions of cognitive workload.

The mean, SD and range values for the baseline and the three experimental conditions are similar to those seen in the normal conditions. The normative data is as given by Anitha (1994).

Also statistical analysis revealed no significant difference between the baseline and experimental conditions for this parameter. However, the values for phonation of *l\l* by females in the first experimental condition (i.e. tongue twister task) were found to be lower than those in the baseline condition for females. This difference was also statistically significant. But since, this is only one value showing significant difference, it is not valid.

6) Fundamental Tremor Frequency (FF tr) :-

It is the frequency of the most intensive low frequency fundamental modulating component in the specified Fo tremor analysis range. Table VI presents the mean, SD and range of FFtr for baseline condition and the three experimental conditions.

The table also gives the Z-values which are obtained by compairing the three experimental conditions with the baseline. Also significant difference between the baseline and experimental conditions is indicated in the table.

As seen from the table, the mean, SD and range values are within the normal limits (Anitha, 1994).

Also, no significant difference was revealed on statistical analysis between the experimental and the baseline conditions for both male and female populations.

Table - V :- Standard Deviation of fundamental frequency (STD) values for males and females in the baseline and experimental conditions.

CONDITIONS	*MALES*			*FEMALES*		
	/a/	/i/	/u/	/a/	/i/	/u/
1. Baseline Condition						
Mean	2.12	3.82	7.58	3.45	4.90	4.86
SD	1.69	4.04	1.00	2.87	2.08	2.52
Range	5.65	10.62	3.43	9.66	6.00	7.53
2. Experimental Condition I (Tongue Twister Task)						
Mean	1.97	1.96	2.73	4.01	3.58	4.95
SD	0.95	0.83	2.39	3.93	1.52	3.23
Range	2.68	2.48	6.57	13.01	5.16	10.18
Z- value	0.96	0.24	0.80	0.44	0.01	0.20
3. Experimental Condition II (Tongue Twister with DAF Task)						
Mean	2.00	2.52	2.01	2.85	4.45	3.95
SD	0.90	1.58	0.72	0.90	1.91	2.10
Range	2.33	5.49	2.49	3.01	6.97	6.07
Z- value	0.65	0.80	0.50	0.95	0.57	0.64
4. Experimental condition 111 (Reverse spelling Task)						
Mean	1.96	2.17	2.85	4.15	3.97	4.57
SD	0.72	0.97	2.16	2.82	2.19	2.37
Range	1.85	2.24	6.68	7.46	7.78	6.13
Z- Value	0.79	0.33	0.79	0.65	0.20	0.88

GRAPH V - Mean Values of Vowles /a/, /i/ & /u/ for males and females of the Standard Deviation of Fundamental Frequency

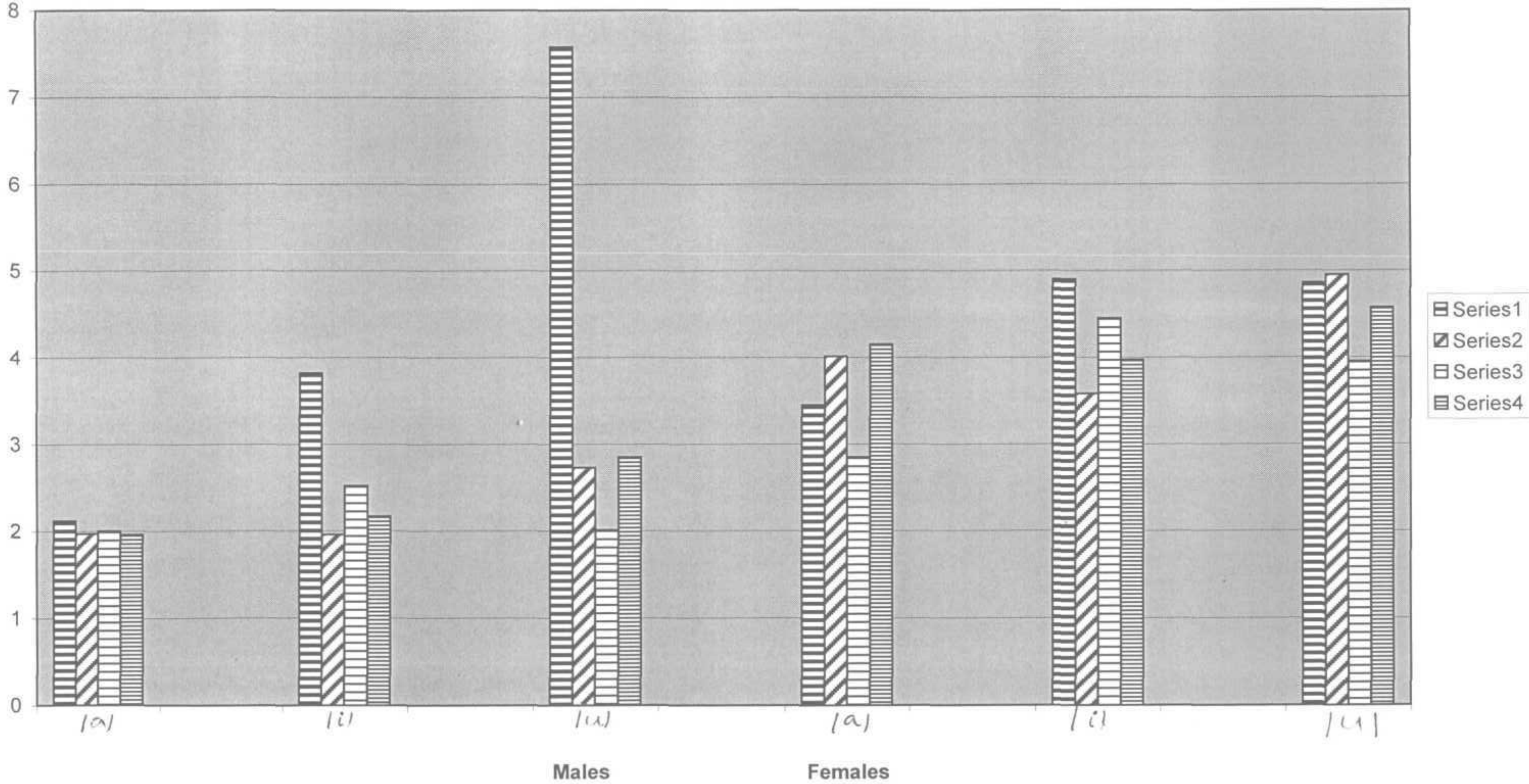
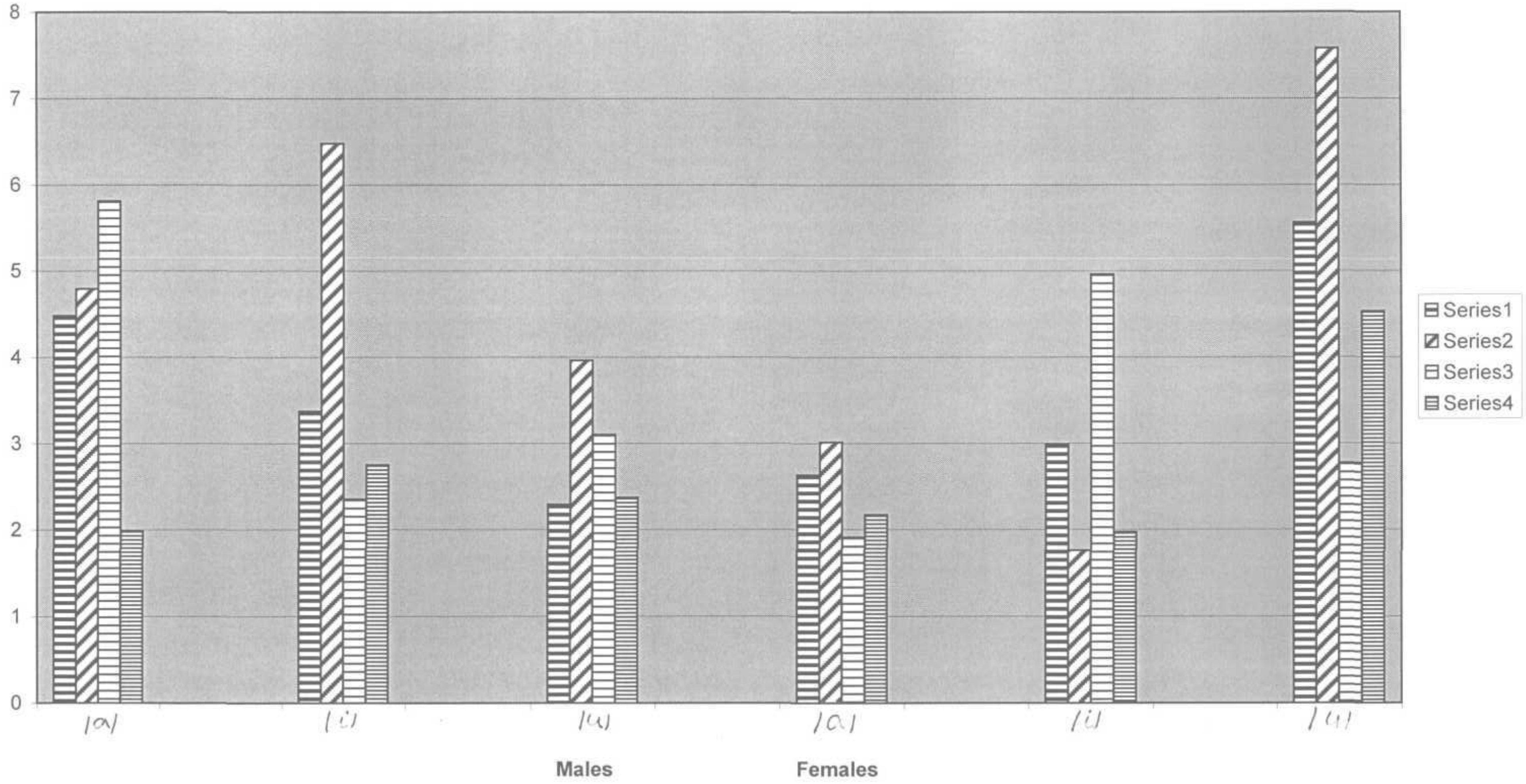


Table -VI:- Fundamental Tremor frequency (FFtr) values for both males and females in the baseline and the experimental conditions.

CONDITIONS	*MALES*			*FEMALES*		
	/a/	/i/	/u/	/a/	/i/	/u/
1. *Baseline Condition*						
Mean	4.48	3.37	2.29	2.63	2.99	5.56
SD	2.59	2.67	1.83	2.05	2.99	7.99
Range	9.03	8.22	6.56	5.43	8.51	21.11
2. *Experimental Condition I (Tongue Twister Task)*						
Mean	4.79	6.48	3.96	3.01	1.76	7.58
SD	3.53	6.04	4.57	3.32	0.84	9.14
Range	9.79	20.38	11.09	11.43	2.05	20.91
Z- value	0.96 (-)	0.83 (-)	0.39 (-)	1.00 (-)	0.51 (-)	0.95 (-)
3. *Experimental Condition II (Tongue Twister with DAF Task)*						
Mean	5.81	2.35	3.10	1.91	4.96	2.77
SD	5.60	1.38	1.75	0.96	6.63	1.65
Range	17.09	4.53	5.28	3.81	17.07	4.76
Z- value	0.50 (-)	0.22 (-)	1.00 (-)	0.72 (-)	0.50 (-)	0.79 (-)
4. *Experimental condition III (Reverse spelling Task)*						
Mean	1.99	2.75	2.37	2.17	1.97	4.58
SD	2.17	1.06	1.65	1.33	1.98	6.26
Range	7.55	3.55	5.43	3.90	5.63	15.65
Z- Value	0.31 (-)	0.50 (-)	0.89 (-)	0.44 (-)	0.57 (-)	0.39 (-)

GRAPH VI - Mean Values of Vowels /a/, /i/ & /u/ for males and females of the Fundamental Tremor frequency



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7) Amplitude Tremor Frequency (Fatr):-

It is defined as the frequency at the most intensive low frequency modulating component in the specified amplitude tremor frequency analysis range. Table VII gives the mean, SD and range values of Fatr for baseline condition and the three experiemental conditions for both males and females.

The results of the statistical analysis are also given as Z-values. Any, significant difference between the baseline and the three experimental conditions is also indicated with +/- (indicating presence or absence of differnece, respectively)

The mean, SD and the range values are found to be within normal limits for both males and females in the baseline as well as the three experimental conditions.

Also no significant difference was observed on compairing the three experimental conditions with the baseline for both male and female groups.

Hence, the parameter of amplitude tremor frequency does not differentiate between the normal and stressed conditions. Also, inducing stress with cognitive workload tasks has no change in this parameter.

8) **Absolute Jitter (Jita)**:

It is an evaluation of the period to period inability of the pitch period within the analyzed voice sample. Jita values were thus obtained during the phonation of the vowels in baseline and experimental conditions.

Table VIII shows the mean, SD and range values of Jita for baseline condition and the three experimental conditons for both males and females. The table also gives theZ-values for the experimental conditions when compared with the baseline. Any significant difference, if any, is also indicated for both males and females.

As seen from the table, Jita mean and SD values are slightly higher than those of the normals, given by Anitha (1994), even in the baseline condition. Even the range has increased slightly in the baseline condition for both males and females, more so for vowel /i/. Thus, indicating the presence of greater variability under stressed conditions. The values in the other experimental conditions are also similar to those of the baseline, except for the first experimental condition i.e. tongue twister task. In this condition significantly lower Jita values were observed when compared to the baseline. Statistical analysis revealed significant difference between the phonation of vowel /i/ by both males and females in this experimental condition (Z=0.05 for male /i/; Z = 0.02 for female /i/). Other statistical analysis revealed no significant difference.

Lower Jita values in the tongue twister task indicate that this task is not providing any additional stressed quality than that seen for the baseline condition.

Table -VII:- Amplitude Tremor frequency (FAtr) values for both males and females in the baseline and the experimental conditions.

CONDITIONS	*MALES*			*FEMALES*		
	/a/	/i/	/u/	/a/	/i/	/u/
1. Baseline Condition						
Mean	2.99	1.86	1.84	2.63	2.14	1.59
SD	3.71	3.55	4.56	4.75	4.28	2.69
Range	8.33	10.81	14.29	14.82	11.11	8.00
2. Experimental Condition I (Tongue Twister Task)						
Mean	3.49	1.82	1.62	1.48	0.00	2.76
SD	5.02	3.00	2.66	2.50	0.00	4.26
Range	12.50	7.14	6.25	6.45	0.00	11.11
Z- value	0.86 (-)	0.96 (-)	0.69 (-)	0.51 (-)	0.11 (-)	0.89 (-)
3. Experimental Condition II (Tongue Twister with DAF Task)						
Mean	2.35	0.37	1.19	1.97	4.14	1.17
SD	2.36	0.89	2.13	3.97	4.59	2.52
Range	6.56	2.76	5.97	11.77	12.12	6.90
Z- value	0.80 (-)	0.33 (-)	0.17 (-)	0.61 (-)	0.39 (-)	0.50 (-)
4. Experimental condition III (Reverse spelling Task)						
Mean	1.39	0.95	1.55	2.24	0.18	2.95
SD	2.29	1.72	3.01	3.33	0.57	3.42
Range	5.63	4.40	7.64	9.09	1.79	10.26
Z- Value	0.57 (-)	0.20. (-)	0.28 (-)	1.00 (-)	0.11 (-)	0.18 (-)

GRAPH VII - Mean Values of Vowles /a/, /i/ & /u/ for males and females of the Amplitude Tremor Frequency

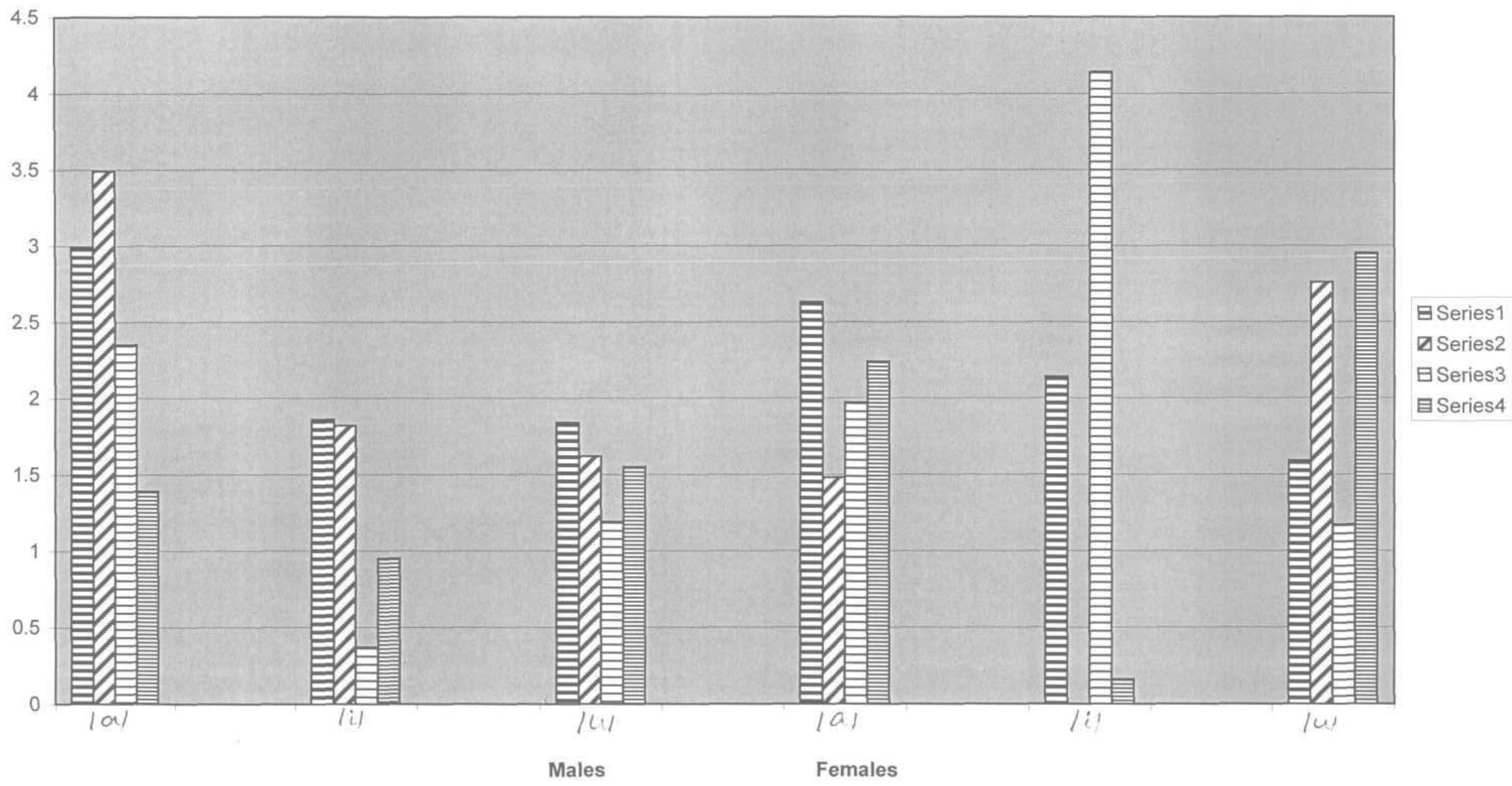
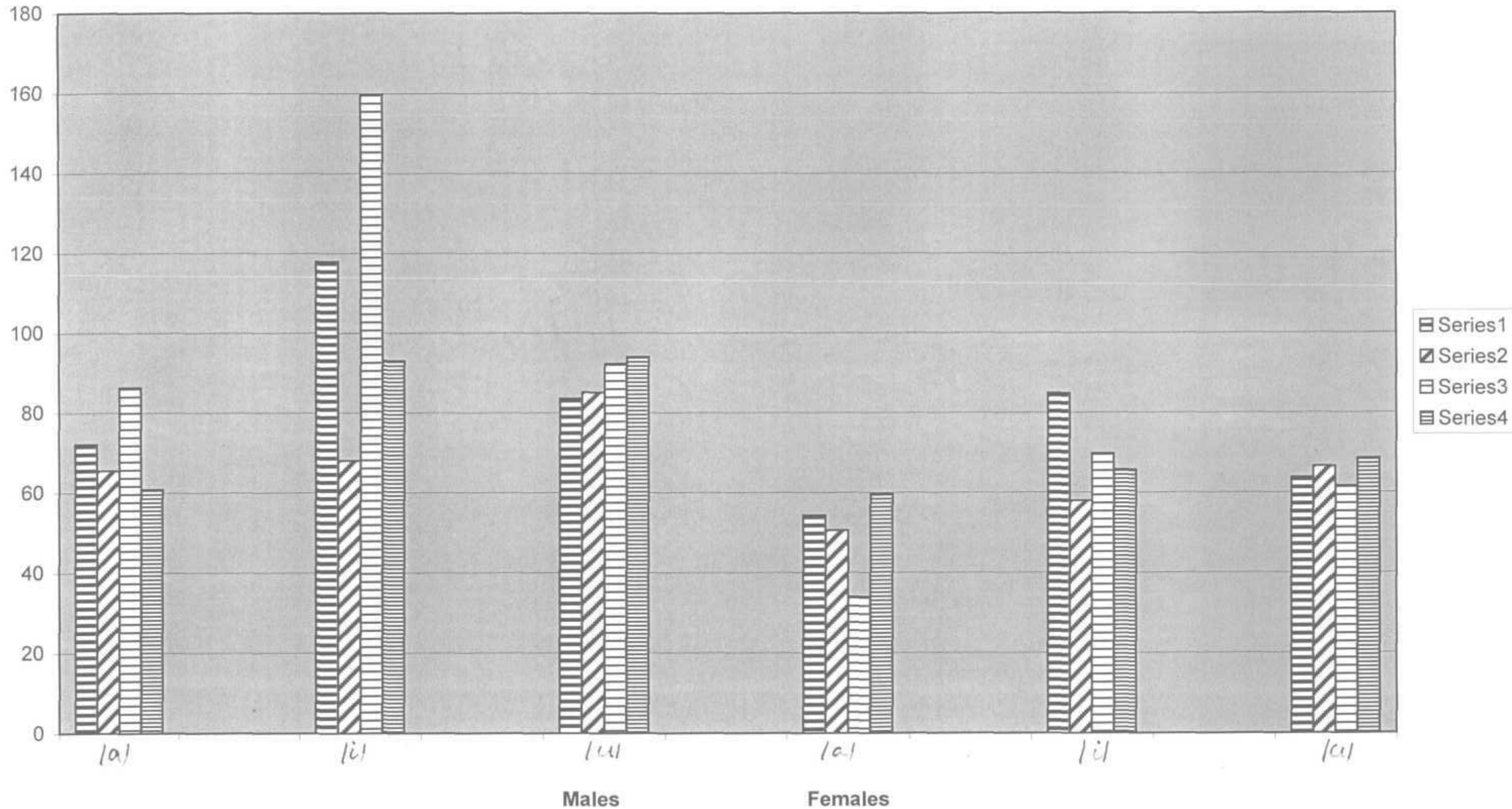


Table -VIII:- Absolute Jitter (Jita) values for both males and females in the baseline and the experimental conditions.

CONDITIONS	MALES			FEMALES		
	/a/	/i/	/u/	/a/	/i/	/u/
1. Baseline Condition						
Mean	72.15	117.90	83.52	54.22	84.85	63.75
SD	35.54	87.94	47.96	47.42	44.28	33.89
Range	109.90	288.16	160.18	138.19	144.36	101.72
2. Experimental Condition I (Tongue Twister Task)						
Mean	65.53	68.02	85.07	50.52	57.93	66.58
SD	35.33	65.60	46.46	36.13	18.45	43.76
Range	116.48	218.80	153.41	120.89	57.49	128.82
Z- value	0.51 (-)	0.05 (-)	0.79 (-)	0.57 (-)	0.02 (-)	0.38 (-)
3. Experimental Condition II (Tongue Twister with DAF Task)						
Mean	86.28	159.74	92.28	33.89	69.76	61.58
SD	77.07	168.74	46.68	13.09	21.17	23.39
Range	266.97	560.09	165.30	41.31	63.98	80.56
Z- value	0.80 (-)	0.96 (-)	0.38 (-)	0.44 (-)	0.64 (-)	0.82 (-)
4. Experimental condition III (Reverse spelling Task)						
Mean	60.84	93.02	93.99	59.67	65.68	68.50
SD	20.19	72.73	59.08	57.55	32.06	42.71
Range	54.16	218.72	162.89	179.35	106.26	136.22
Z- Value	0.50 (-)	0.44 (-)	0.28 (-)	0.88 (-)	0.11 (-)	0.72 (-)

GRAPH VIII - Mean Values of Vowels /a/, /i/ & /u/ for males and females of the Absolute Jitter



9. Jitter Percent (Jitt):-

It is an evaluation of the variability of the pitch period within the analyzed voice sample. It represents the relative period to period(very short term) variability.The mean, SD and range for this parameter are presented in table IX for, the baseline and the three experimental conditions, for both male and female populations.

The table also gives the results of statistical analysis when the values for the experimental conditions were compared with those of the baseline condition. The presence of any significant difference is also shown by +/- (indicating presence or absence of difference respectively).

The table gives the mean SD and range values to be slightly higher when compared to the norms given by Anitha (1994) in the baseline condition. Literature also indicates the mean Jitt values to be within 1 % (Horri, 1982). But higher values are observed in the baseline condition for both males and females. This accounts for the presence of stress which is attributed to the instructions given to the subjects.

However significantly lower values are observed for the phonation of vowel *l\l* in the first experimental condition i.e., tongue twister task (Z for males = 0.06; Z for females = 0. 02). The mean, SD and range values in the other experimental conditions are similar to those in the baseline, for both males and females.

10) Relative Average Perturbation (RAP):-

It is defined as the relative evaluation of the period to period variability of the pitch of the analysed voice sample with smoothing factor of three periods. The mean, SD and range values for the baseline and the three experimental conditions are presented in Table X for both males and females.

The table also shows the Z-values which are obtained by comparing the three experimental conditions with the baseline. Also significant difference between the baseline and experimental conditions is indicated in the table.

The table gives the mean, SD and range values to be within normal limits for both males and females in the baseline condition. Norms as given by Anitha (1994).

The values in the other experimental conditions are also similar to the baseline except in the first experimental condition i.e. the tongue twister task. In this condition lower values are observed for the phonation of /i/ by both males and females, which are also statistically significant (Z = 0.06 for males, Z = 0.02 for females) when compared to the baseline. This is because not much stress is induced in this experimental condition, thus bringing about little change in the physiology of the vocal folds.

Table -IX :- Jitter Percent (Jitt) values for both males and females in the baseline and the experimental conditions

CONDITIONS	*MALES*			*FEMALES*		
	/a/	**/i/**	**/u/**	/a/	/i/	/u/
1. *Baseline Condition*						
Mean	0.94	1.48	1.10	1.34	2.07	1.53
SD	0.49	0.97	0.62	1.25	0.96	0.94
Range	1.40	3.22	1.96	3.83	3.11	2.84
2. *Experimental Condition I (Tongue Twister Task)*						
Mean	0.82	1.11	1.18	1.24	1.43	1.71
SD	0.37	0.68	0.69	0.98	0.44	1.21
Range	1.11	2.15	1.96	3.33	1.40	3.77
Z- value	0.57 (-)	0.06 (-)	0.72 (-)	0.57 (-)	0.02 (-)	0.79 (-)
3. *Experimental Condition II (Tongue Twister with DAF Task)*						
Mean	1.11	2.15	1.28	0.81	1.75	1.60
SD	0.96	2.45	0.74	0.32	0.53	0.68
Range	3.28	6.24	2.66	1.00	1.70	2.29
Z- value	0.96 (-)	0.96 (-)	0.20 (-)	0.44 (-)	0.50 (-)	0.79 (-)
4. *Experimental condition III (Reverse spelling Task)*						
Mean	0.79	1.17	1.29	1.42	1.62	1.72
SD	0.31	0.78	0.80	1.31	0.79	1.03
Range	0.85	2.11	2.34	3.86	2.77	3.07
Z- Value	0.57 (-)	0.50 (-)	0.20 (-)	0.96 (-)	0.11 (-)	0.79 (-)

GRAPH IX - Mean Values of Vowels /a/, /i/ & /u/ for males and females of the Jitter percent

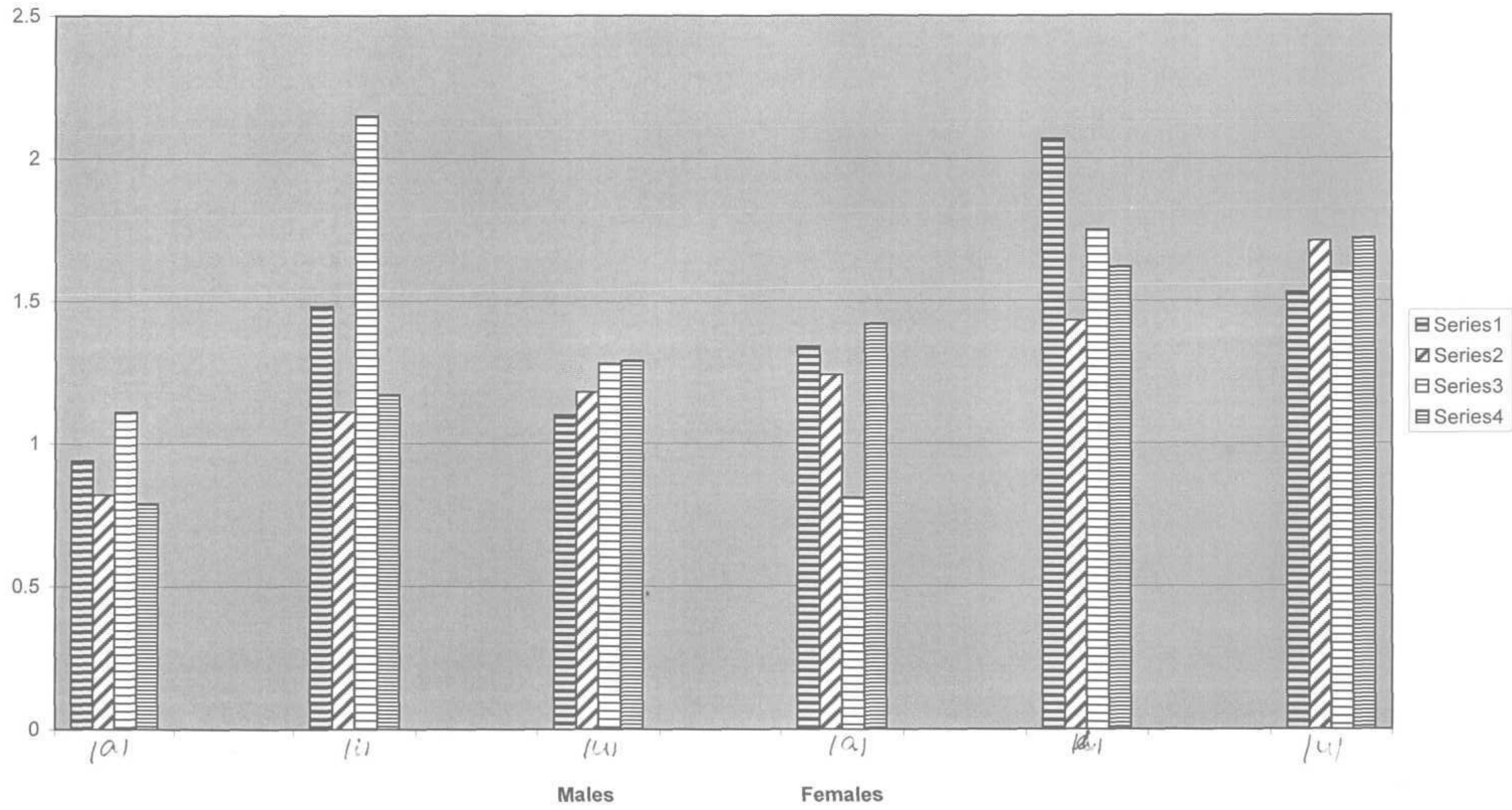
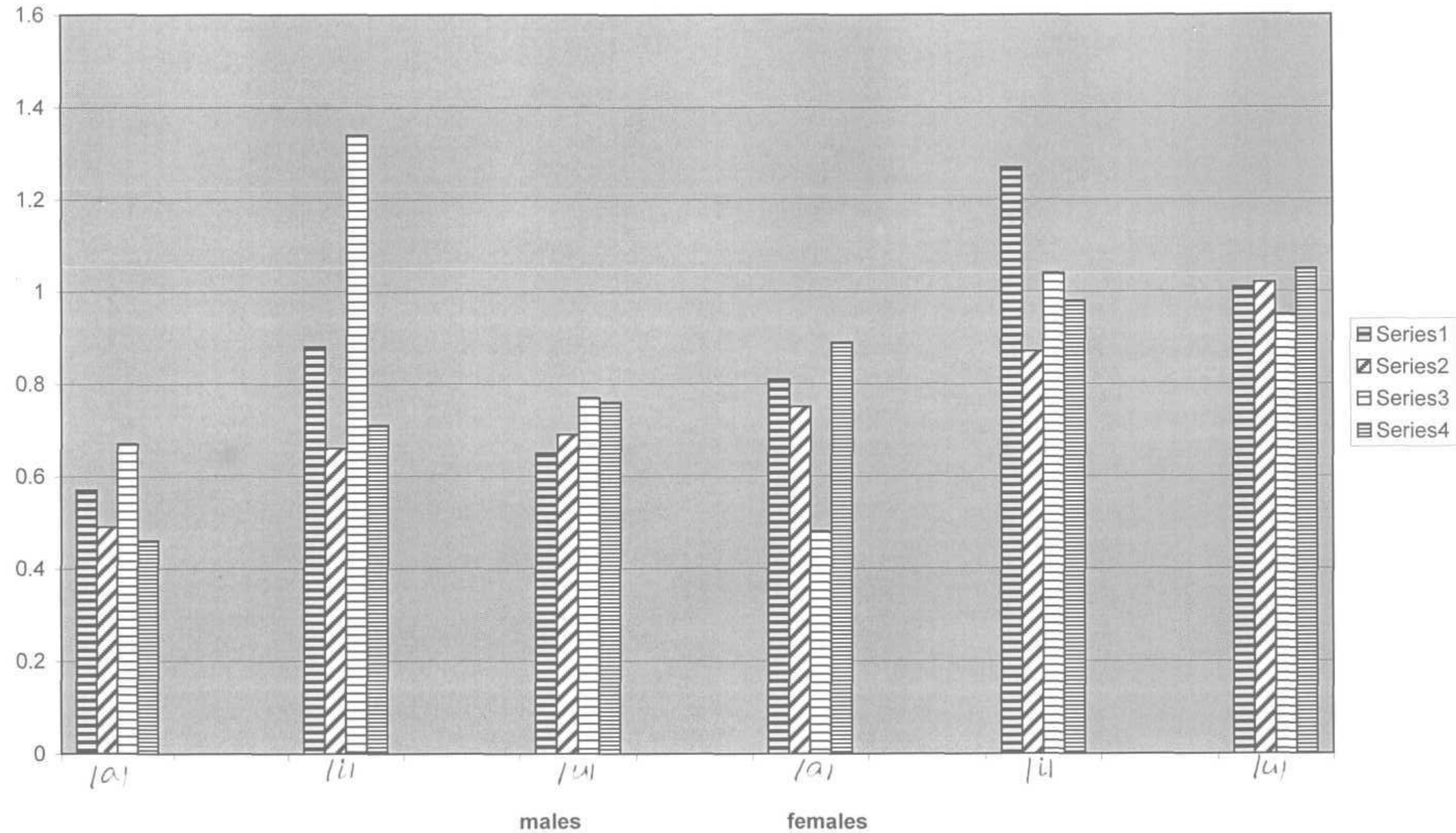


Table-X :- Relative Average Perturbation (RAP) values for **both** males and females in the baseline and the experimental conditions.

CONDITIONS	*MALES*			*FEMALES*		
	/a/	***/i/***	**/u//**	/a/	/i/	/u/
1. *Baseline Condition*						
Mean	0.57	0.88	0.65	0.81	1.27	1.01
SD	0.32	0.56	0.35	0.76	0.62	0.54
Range	0.93	1.81	1.06	2.33	2.00	1.73
2. *Experimental Condition I (Tongue Twister Task)*						
Mean	0.49	0.66	0.69	0.75	0.87	1.02
SD	0.25	0.41	0.42	0.57	0.27	0.71
Range	0.75	1.33	1.18	1.95	0.83	2.09
Z- value	0.58 (-)	0.06 (-)	0.64 (-)	0.57 (-)	0.02 (-)	0.44 (-)
3. *Experimental Condition **II** (Tongue Twister with DAF Task)*						
Mean	0.67	1.34	0.77	0.48	1.04	0.95
SD	0.58	1.66	0.45	0.18	0.31	0.39
Range	1.98	5.57	1.62	0.59	1.00	1.35
Z- value	0.83 (-)	0.95 (-)	0.20 (-)	0.38 (-)	0.44 (-)	0.57 (-)
4. *Experimental condition **III** (Reverse spelling Task)*						
Mean	0.46	0.71	0.76	0.89	0.98	1.05
SD	0.20	0.47	0.47	0.84	0.47	0.65
Range	0.56	1.26	1.35	2.53	1.61	2.01
Z- Value	0.51 (-)	0.44 (-)	0.17 (-)	0.96 (-)	0.11 (-).	0.96 (-)

GRAPH X - Mean Values of Vowels /a/, /i/ & /u/ for males and females of the Relative Average Perturbation



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11) Pitch Perturbation Quotient (PPQ):-

It is the relative evaluation of the period to period variability of the pitch within the analysed voice sample with a smoothing factor of five periods.

The mean, SD and range values for the baseline and the three experimental conditions are presented in table XI for both males and females. The table also shows the Z-values and the significant difference if any, between the baseline and three experimental conditions of cognitive work load.

The table shows the mean, SD and range values to be within normal limits for both males and females in the baseline condition. The values in the other three experimental conditions are also similar to those of the baseline for both males and females. However, lower values are observed for the phonation of vowel *!\!* in the first experimental condition i.e. Tongue Twister task (Z for males — 0.06; Z for females = 0.04).

12. Smoothed Pitch Period Perturbation Quotient (SPPQ):

It is the relative evaluation of the short or long term variability of the pitch period within the analysed voice sample with a smoothing factor defined by the user.

Table XII represents the mean, SD and range values of males and females for the baseline and the three experimental conditions.

The table also shows the Z-values which are obtained when the experimental conditions were compared with the baseline condition. Significant difference, if any, is also indicated by +/- sign, referring presence of absence of difference respectively.

As seem from the table, in the baseline condition mean, SD and range values are higher, for the phonation of vowel /i/, by both males and females. This is in comparison with the norms given by Anitha (1994). These higher values can be attributed to the physiological changes owing to the stress (Scherer, 1986) presented through the instructions.

Also, higher values are maintained across the experimental conditions. These are similar to those of the baseline and do not show any significant difference when compared to the baseline.

However, significantly lower values are observed for phonation of vowel *I'll* by females in the first experimental condition i.e. the tongue twister task (Z=0.05). This being only one value that is showing a significant difference is not valid.

Table -XI:- Pitch Perturbation Quotient (PPQ) values for both males and females in the baseline and the experimental conditions

CONDITIONS	*MALES*			*FEMALES*		
	/a/	*/i/*	**/u/**	**/a/**	*/i/*	*/u/*
1. *Baseline Condition*						
Mean	0.49	0.84	0.65	0.79	1.14	**0.88**
SD	0.22	0.52	0.34	0.74	0.42	**0.42**
Range	0.56	1.75	1.07	2.23	1.33	1.30
2. *Experimental Condition I (Tongue Twister Task)*						
Mean	0.46	0.65	0.66	0.72	0.84	0.99
SD	0.19	0.38	0.35	0.61	0.26	0.73
Range	0.54	1.22	1.09	2.07	0.82	2.46
Z- value	0.72 (-)	0.06 (-)	0.80 (-)	0.24 (-)	0.04 (-)	0.95 (-)
3. *Experimental Condition II (Tongue Twister with DAF Task)*						
Mean	0.62	1.08	0.75	0.48	0.98	0.98
SD	0.53	0.92	0.43	0.18	0.43	0.42
Range	1.83	3.13	1.55	0.58	1.63	1.40
Z- value	0.95 (-)	0.80 (-)	0.26 (-)	0.38 (-)	0.44 (-)	0.57 (-)
4. *Experimental condition III (Reverse spelling Task)*						
Mean	0.67	0.65	0.75	0.78	0.91	0.96
SD	**0.18**	0.41	0.52	0.66	0.42	0.53
Range	**0.51**	1.14	1.58	1.73	1.57	1.45
Z- Value	0.65 (-)	0.33 (-)	**0.17** (-)	0.96 (-)	0.09 (-)	**0.65** (-)

GRAPH XI - Mean Values of vowels /a/, /i/ & /u/ for males and females of Pitch perturbation quotient

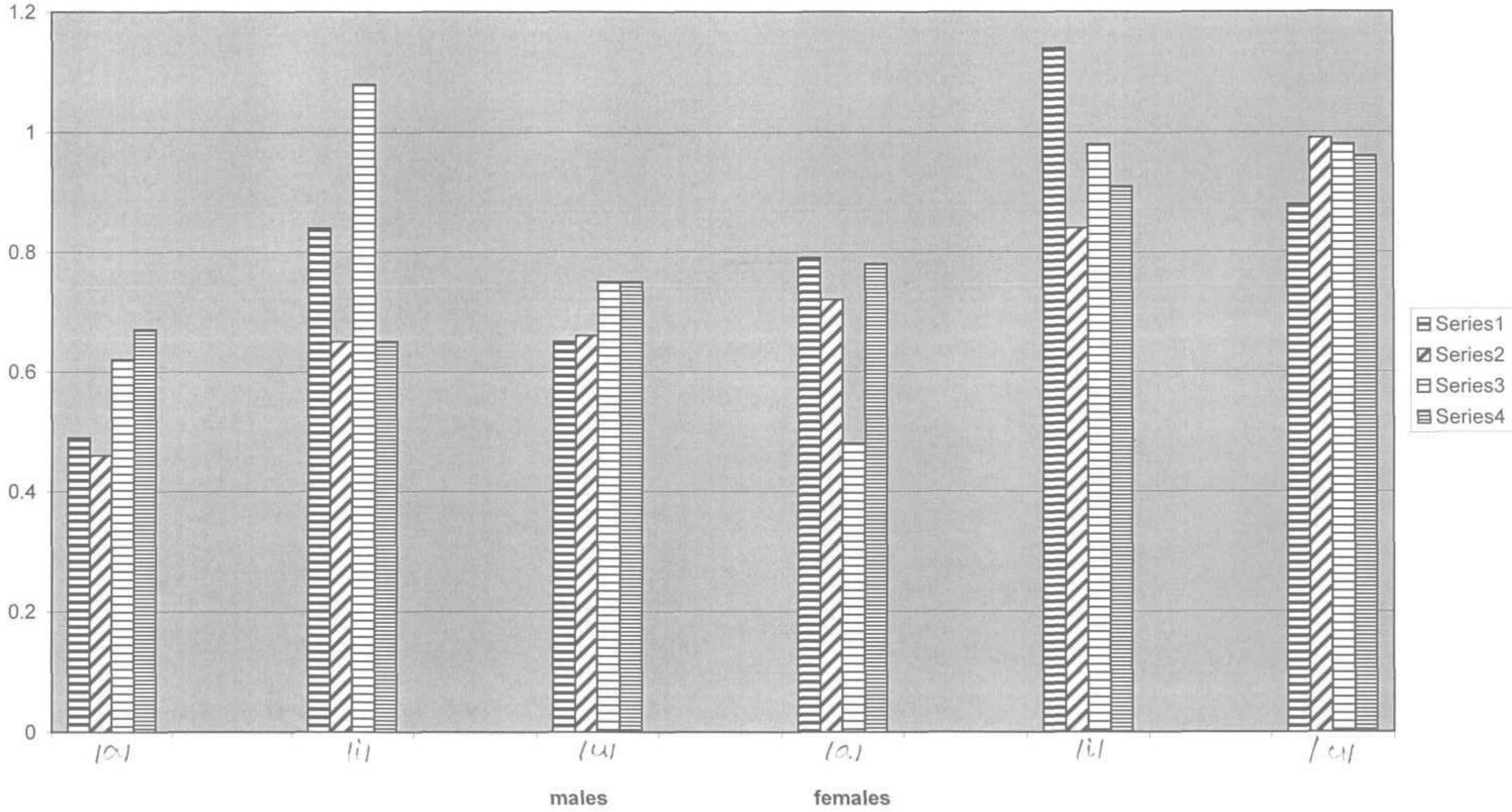
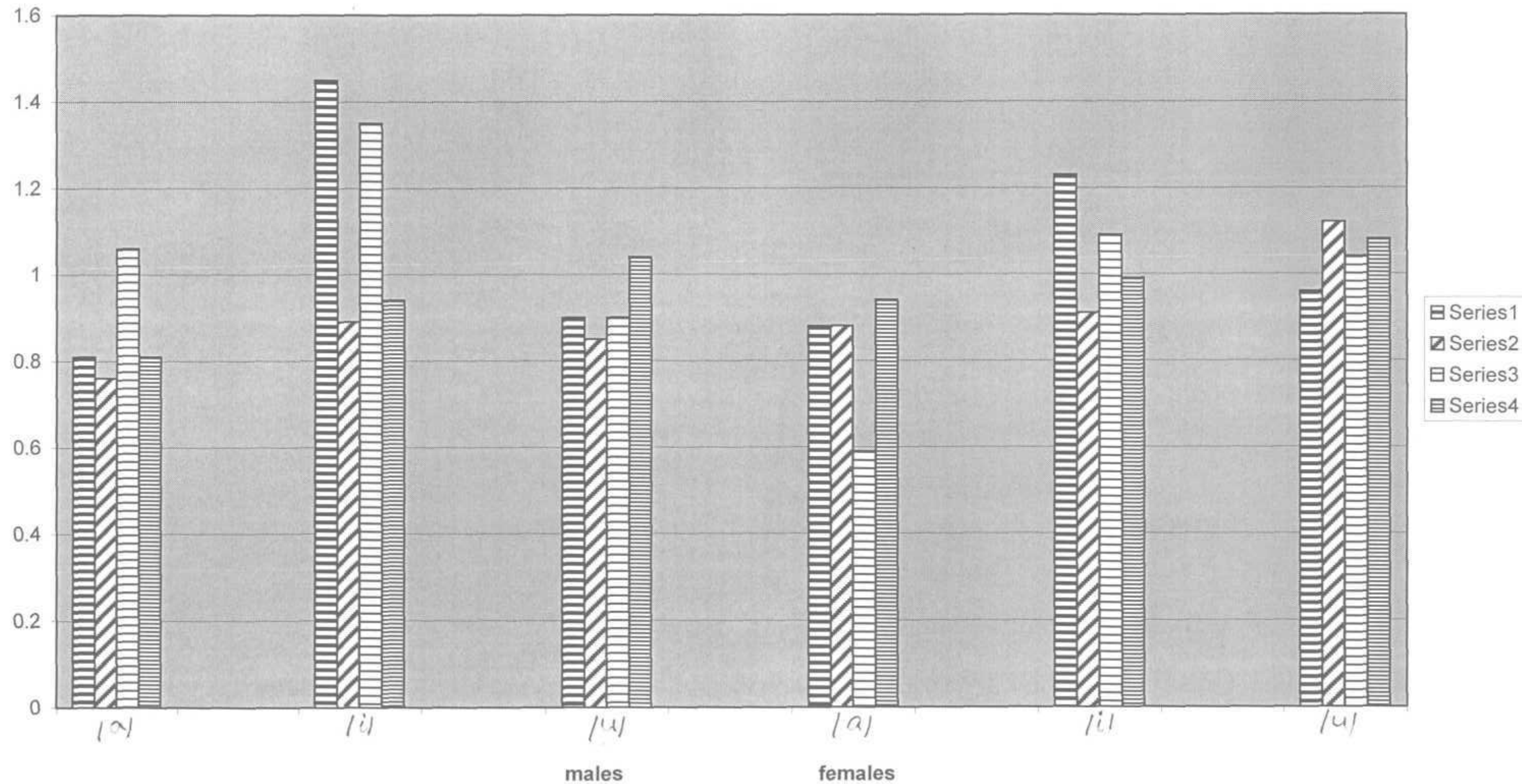


Table -XII:- Smoothed Pitch period Perturbation Quotient (SPPQ) values for both males and females in the baseline and the experimental conditions.

CONDITIONS	*MALES*			*FEMALES*		
	/a/	/i/	/u/	/a/	/i/	/u/
1. Baseline Condition						
Mean	0.81	1.45	0.90	0.88	1.23	0.96
SD	0.32	1.47	0.33	0.69	0.52	0.37
Range	1.14	4.79	1.07	2.15	1.66	1.24
2. Experimental Condition I (Tongue Twister Task)						
Mean	0.76	0.89	0.85	0.88	0.91	1.12
SD	0.14	0.37	0.26	0.68	0.30	0.70
Range	0.37	1.16	0.90	2.34	0.91	2.31
Z- value	0.96 (-)	0.24 (-)	0.88 (-)	0.64 (-)	0.05 (-)	0.33 (-)
3. Experimental Condition II (Tongue Twister with DAF Task)						
Mean	1.06	1.35	0.90	0.59	1.09	1.04
SD	1.01	1.16	0.30	0.16	0.37	0.42
Range	3.42	3.98	0.99	0.49	1.31	1.39
Z- value	0.96 (-)	0.96 (-)	0.86 (-)	0.38 (-)	0.57 (-)	0.72 (-)
4. Experimental condition III (Reverse spelling Task)						
Mean	0.81	0.94	1.09	0.94	0.99	1.08
SD	0.15	0.48	0.48	0.69	0.47	0.57
Range	0.46	1.30	1.21	1.97	1.62	1.65
Z- Value	0.61 (-)	0.49 (-)	0.14 (-)	0.96 (-)	0.20 (-)	0.45 (-)

GRAPH XII - Mean Values of Vowels /a/, /i/ & /u/ for males and females of smoothed pitch period perturbation quotient



13. Co-efficient of Fundamental Frequency Variation (VFo)

This is defined as relative standard deviation of the Fo and it reflects, in general the variation of Fo. The mean, SD and range values are presented in Table XIII, for both male and female for the baseline and the three experimental conditions. The table also give the Z-values which are obtained by comparing the three experimental conditions with the baseline. Also significant difference between the baseline and experimental conditions is indicated in the table.

It is seen from the table that the mean, SD and Range values are higher in the baseline condition when compared with the norms given by Anitha (1994). This increased variability in fundamental frequency, as indicated by V Fo, can be attributed to the physiological changes brought about due to the presence of stress (Scherer, 1986).

However, tasks of cognitive workload does not provide any excess amount of stress as indicated by the similar values in the three experimental conditions for both males and females. The table shows the mean, SD and range values for the three experimental conditions, to be similar to those of the baseline and also no significant difference is found between the baseline and the experimental conditions on statistical analysis.

14. Shimmer in (IB (shdB):

This is a measure of very short term (cycle to cycle) irregularity of the peak to peak to peak amplitude of the voice. The mean, SD and range are presented in Table XIV for baseline and the three experimental conditions for both males and females.

The Z-values given are obtained by comparing the measures of the three experimental conditions with those of the baseline. These values are given for the experimental conditions and the significant difference with the baseline is also indicated.

The mean, SD and range values in the baseline condition as seen from the table, are found to be greater when compared to the normative values given by Anitha, 1994. These are similar to those of the dysphonics as given by Gopalkrishna, 1995. This it can be stated that the presence of stress brings about greater variability in terms of amplitude of voice.

The values for the other three experimental conditions are similar to those of the baseline for both males and females, thus indicating greater irregularity. No statistically significant difference was obtained when the respective values in the three experimental conditions were compared with those of the baseline, except in the second experimental condition. In the tongue twister with DAF task still higher values were obtained /or phonation of /a/ by males which were also statistically significant (Z = 0.01) when compared with the baseline. However, this being only one value that is showing a difference, is not valid.

Thus, the tasks of cognitive workload, do not provide any excess amount of stress than that seen in the baseline condition.

Table -XIII:- Co-efficient of fundamental frequency variation (Vfo) Values for both males and females in the baseline and the three experimental conditions .

CONDITIONS	*MALES*			*FEMALES*		
	/**a**/	/**i**/	/u/	/a/	/i/	/u/
1. *Baseline Condition*						
Mean	1.58	2.86	1.98	1.39	1.97	**1.89**
SD	1.01	3.03	1.49	1.05	0.37	0.96
Range	3.38	9.04	5.04	3.49	2.44	2.81
2. *Experimental Condition I (Tongue Twister Task)*						
Mean	1.48	1.37	1.94	1.62	1.43	1.91
SD	0.68	**0.54**	**1.63**	1.42	0.58	1.12
Range	1.81	1.48	5.12	4.75	2.01	3.45
Z- value	0.80 (-)	0.203 (-)	0.88 (-)	0.28 (-)	0.20 (-)	0.20 (-)
3. *Experimental Condition II (Tongue Twister with DAF Task)*						
Mean	3.61	1.86	1.45	1.18	1.75	1.85
SD	6.93	1.08	0.40	0.35	0.72	0.85
Range	2.48	3.72	1.12	1.27	2.59	3.07
Z- value	0.72 (-)	0.72 (-)	0.44 (-)	0.79 (-)	0.57 (-)	0.95 (-)
4. *Experimental condition III (Reverse spelling Task)*						
Mean	1.48	**1.49**	1.97	1.74	1.59	1.79
SD	0.38	0.86	1.23	1.17	0.83	0.88
Range	0.98	2.45	3.33	3.41	2.98	2.11
Z- Value	**0.88** (-)	**0.33** (-)	0.96 (-)	0.52 (-)	0.20 (-)	0.96 (-)
.						

GRAPH XIII - Mean Values of Vowels /a/, /i/, & /u/ for males and females of the variation of fo

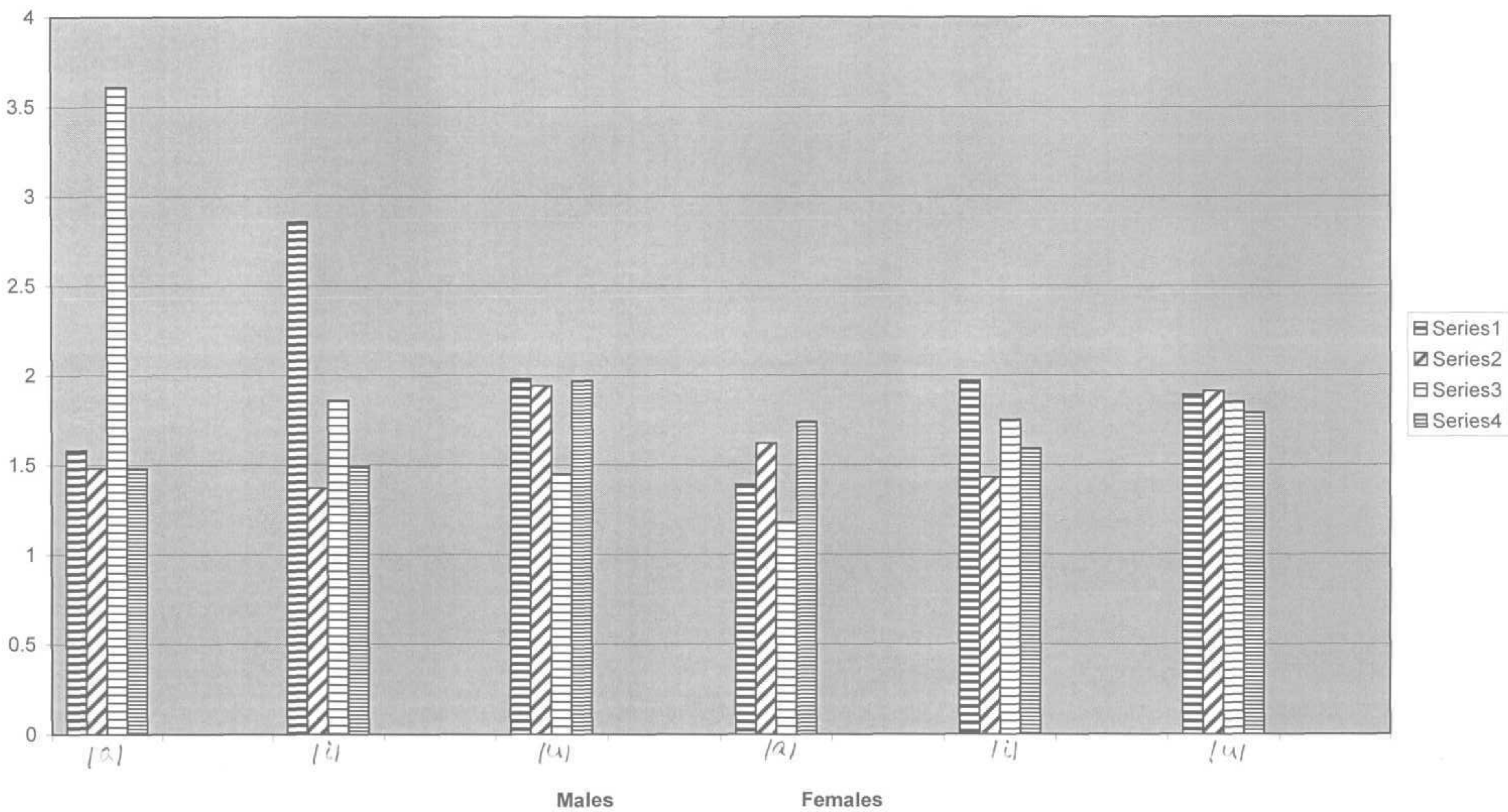
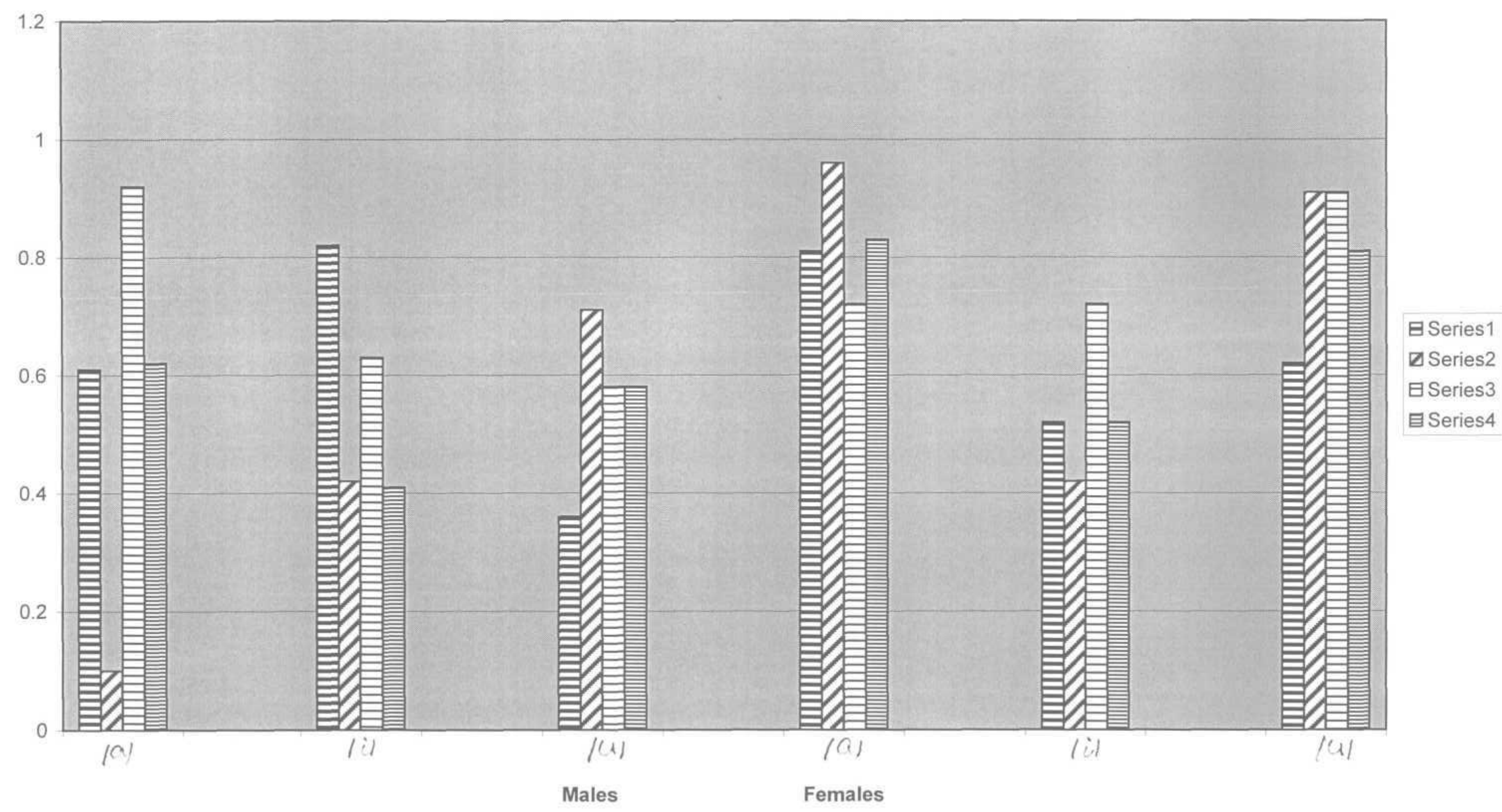


Table -XIV :- Shimmer in dB (ShdB) values for both males and females in the baseline and the experimental conditions.

CONDITIONS	*MALES*			*FEMALES*		
	/a/	/i/	/u/	/a/	/i/	/u/
1. *Baseline Condition*						
Mean	0.61	0.82	0.36	0.81	0.52	0.62
SD	0.23	0.92	0.19	0.66	0.32	0.56
Range	0.56	0.29	0.68	0.17	0.12	0.17
2. *Experimental Condition I (Tongue Twister Task)*						
Mean	0.10	0.42	0.71	0.96	0.42	0.91
SD	0.13	0.18	0.18	0.70	0.23	0.11
Range	0.45	0.04	0.33	0.19	0.06	0.28
Z- value	0.57 (-)	0.11 (-)	0.72 (-)	0.28 (-)	0.58 (-)	0.87 (-)
3. *Experimental Condition II (Tongue Twister with DAF Task)*						
Mean	0.92	0.63	0.58	0.72	0.72	0.91
SD	0.31	0.42	0.43	0.41	0.36	0.90
Range	0.12	0.14	0.15	0.17	0.09	0.27
Z- value	0.01 (+)	0.95 (-)	0.44 (-)	0.64 (-)	0.12 (-)	0.38 (-)
4. *Experimental condition III (Reverse spelling Task)*						
Mean	0.62	0.41	0.58	0.83	0.52	0.81
SD	0.36	0.24	0.51	0.83	0.42	0.72
Range	0.11	0.09	0.15	0.27	0.15	0.18
Z- Value	0.80 (-)	0.13 (-)	0.51 (-)	0.28 (-)	0.95 (-)	0.64 (-)

GRAPH XIV- Mean values of vowels /a /,/i/ &/u/ for males and females of the shimmer in dB



15. Shimmer in percent (Shim):

It is the relative period to period (very short term) variability of the peak to peak amplitude. The mean, SD and range for the baseline and three experimental conditions are presented in table XV for both male and female subjects.

The table also gives the Z values which are obtained by comparing the respective measures of the experimental conditions with those of the baseline condition for both males and females. Significant difference, if any, is also indicated.

The mean, SD and range values are lower when compared to the normals for both males and females in the baseline condition. This can be attributed to the measurement variability.

The mean, SD and range values are similar to those in the baseline condition for the first experimental condition. No significant difference is also observed on statistical analysis.

In the second experimental condition the mean, SD and range values are comparatively higher when compared to those of the baseline. Also statistical analysis revealed significant difference between baseline and this experimental condition for phonation of /a/ by males (z=0.01) and phonation of /i/ by females (z=0.06). Thus indicating greater amplitude variability due to lombard and the stressed conditions in this experimental task.

Mean, SD and range values in the third experimental condition are similar to those seen in the baseline and also no significant difference was observed on statistical analysis.

16. Amplitude perturbation Quotient (APQ)

APQ is defined as relative evaluation of the period to period variability of the peak to peak amplitude within the analysed voice sample of a smoothing factor of 11 periods. Table XVI shows the mean, SD and range values of males and females for the baseline condition and the three experimental conditions.

The table also gives the Z scores when the three experimental conditions are compared with the baseline. Any significant difference is also indicated.

The mean, SD and range values are lower than the normal limits (Anitha, 1994) for both males and females in the baseline condition. This is due to the measurement variability.

The mean, SD and range values in the first experimental condition are similar to those seen in the baseline. The statistical analysis revealed significant difference between the baseline and reading of the tongue twister with DAF condition for phonation of /i/ by female subjects (Z-0.06). The level of significance for male phonation of vowel /a/ is at 0.09, thus tending towards significant difference. These higher values indicate greater amplitude variability due to the lombard effect and the presence of stress in this condition

Table -XV :- Shimmer in percent (Shim) values for both males and females in the baseline and the experimental conditions.

CONDITIONS	*MALES*			*FEMALES*		
	/a/	/i//	/u/	/a/	/i/	/u/
1. Baseline Condition						
Mean	0.75	0.84	0.57	0.95	0.62	0.67
SD	0.20	0.78	0.39	0.74	0.38	0.51
Range	0.60	2.40	1.31	2.01	1.27	1.70
2. Experimental Condition I (Tongue Twister Task)						
Mean	0.69	0.48	0.62	0.91	0.49	1.04
SD	0.24	0.15	0.43	0.66	0.23	1.04
Range	0.82	0.48	1.34	1.73	0.66	2.64
Z- value	0.80 (-)	0.11 (-)	0.88 (-)	0.28 (-)	0.62 (-)	0.79 (-)
3. Experimental Condition II (Tongue Twister with DAFTask)						
Mean	1.03	0.71	0.59	0.89	0.89	1.04
SD	0.33	0.46	0.34	0.54	0.42	1.00
Range	1.19	1.57	1.08	1.83	1.00	2.91
Z- value	0.01 (+)	0.96 (-)	0.88 (-)	0.57 (-)	0.06 (+)	0.20 (-)
4. Experimental condition III (Reverse spelling Task)						
Mean	0.72	0.43	0.67	1.07	0.62	0.95
SD	0.24	0.19	0.58	0.95	0.51	0.82
Range	0.86	0.66	1.58	3.15	1.74	2.06
Z- Value	0.80 (-)	0.11 (-)	0.57 (-)	0.28 (-)	0.88 (-)	0.44 (-)

GRAPH XV - Mean Values of Vowels /a/, /i/ & /u/ for males and females of the shimmer in percent

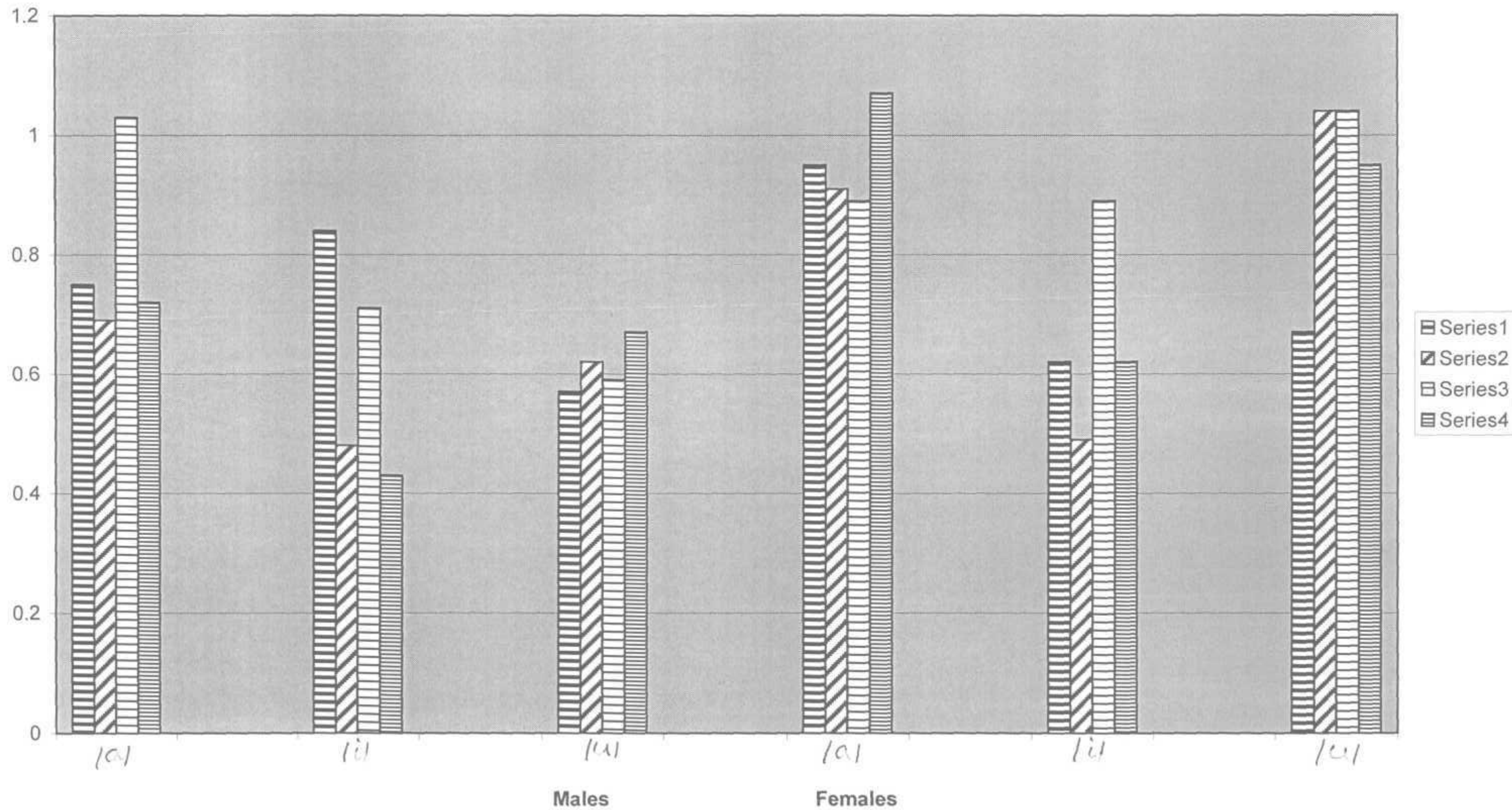
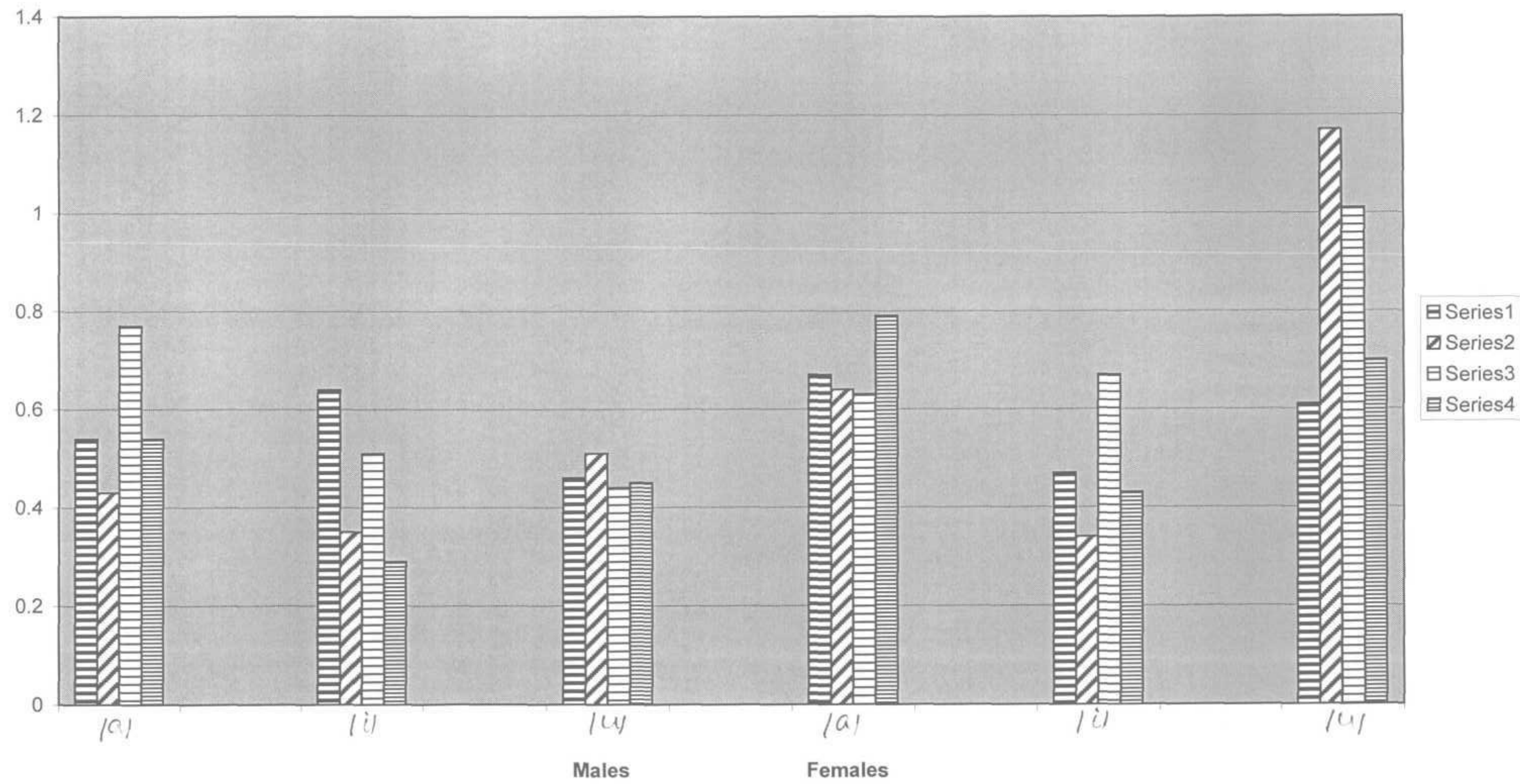


Table -XVI:- Average Perturbation Quotient (APQ) values for both males and females in the baseline and the experimental conditions

CONDITIONS	*MALES*			*FEMALES*		
	/a/	/i/	/u//	/a/	/i/	/u/
1. Baseline Condition						
Mean	0.54	0.64	0.46	0.67	0.47	0.61
SD	0.16	0.65	0.48	0.53	0.35	0.75
Range	0.51	2.06	1.61	1.47	1.12	2.51
2. Experimental Condition I (Tongue Twister Task)						
Mean	0.43	0.35	0.51	0.64	0.34	1.17
SD	0.19	0.12	0.48	0.48	0.16	1.44
Range	0.69	0.38	1.61	1.25	0.45	3.52
Z- value	0.44 (-)	0.13 (-)	0.79 (-)	0.28 (-)	0.36 (-)	0.79 (-)
3. Experimental Condition II (Tongue Twister with DAF Task)						
Mean	0.77	0.51	0.44	0.63	0.67	1.01
SD	0.22	0.35	0.31	0.39	0.34	1.13
Range	0.82	1.22	0.96	1.32	0.83	2.93
Z- value	0.09 (-)	0.64 (-)	0.72 (-)	0.57 (-)	0.06 (-)	0.13 (-)
4. Experimental condition III (Reverse spelling Task)						
Mean	0.54	0.29	0.45	0.79	0.43	0.70
SD	0.19	0.12	0.36	0.68	0.35	0.66
Range	0.60	0.38	1.01	2.28	1.20	1.62
Z- Value	0.92 (-)	0.09 (-)	0.72 (-)	0.28 (-)	0.72 (-)	0.65 (-)

GRAPH XVI - Mean Values of Vowels /a/, /i/ & /u/ for males and females of the average perturbation quotient



In the third experimental condition mean, SD and range values are almost similar to those in the baseline condition. The level of significance for phonation of /i/ by males is 0.09. Thus it is tending towards showing a significant difference for baseline and condition of spelling of the English word in reverse order. However, this being only one value is not valid.

17. Smoothed Amplitude perturbation Quotient (SAPQ):

This is the relative evaluation of the short or long term variability of the peak to peak amplitude with in the analysed voice sample at smoothing factor defined by the user, excluding the voice breaks.

The mean, SD and range for the baseline condition are presented in table XVII for baseline and the three experimental conditions for both male and female subjects. The table also shows the Z values which are obtained when the experimental conditions were compared with the baseline condition. Significant difference, if any, is also indicated by +/- sign, referring presence or absence of difference respectively.

The table shows that the mean, SD and range values are lower than those seen in the normals for the baseline condition (Anitha 1994). This can be due to measurement variability. Also the SAPQ values in the three experimental conditions are similar to those seen in the baseline, except for those in the second experimental condition.

In this task of reading of tongue twister with DAP, significantly higher values are observed for the phonation of/a/ by males (Z = 0.02) and the phonation of /i/ by females (Z = 0.05). These can be attributed to the lombard effect and also the stressed condition, causing greater amplitude variability. No other significant difference was observed on statistical analysis.

18. Co-efficient of Amplitude Variation (Vam):

Vam is defined as relative standard deviation of the peak to peak amplitude. The table XVIII presents the mean, SD and range values for males and females for the baseline condition and the three experimental conditions. The table also shows the Z values and the significant difference if any, between the baseline and the three experimental conditions of cognitive workload.

The mean, SD and Range values are observed to be lower for both males and females in the baseline condition (Anitha 1994). This could be attributed to the measurement variables.

The mean, SD and Range values for phonation of/u/ by females are higher in the first and second experimental condition when compared to the baseline. This could be attributed to the presence of stress bringing about physiological changes in vocal folds (Scherer, 1986) and the lombard effect due to be present in Tonge Twister with DAF task. However, these differences are not statistically significant and bring only one vowel phonation, it is not valid.

Table -XVTI:- Smoothed Amplitude Perturbation Quotient (SAPQ) values for both males and females in the baseline and the experimental conditions

CONDITIONS	*MALES*			*FEMALES*		
	/a/	/i/	**/u/**	/a/	/i/	/u/
1. Baseline Condition						
Mean	0.65	1.01	0.66	0.72	**0.54**	0.85
SD	0.20	1.24	0.83	0.55	0.49	**1.27**
Range	0.64	3.69	2.74	1.54	1.60	4.21
2. Experimental Condition I (Tongue Twister Task)						
Mean	0.61	0.43	0.67	0.83	0.38	**1.63**
SD	0.16	0.16	0.82	0.69	0.19	2.12
Range	0.44	0.61	2.74	1.92	0.59	**5.71**
Z- value	0.96 (-)	0.17 (-)	0.79 (-)	0.51 (-)	0.20 (-)	0.72 (-)
3. Experimental Condition II (Tongue Twister with DAF Task)						
Mean	0.89	0.57	0.48	0.75	0.75	1.45
SD	0.24	0.32	0.26	0.62	0.40	**1.74**
Range	**0.89**	1.07	0.82	2.06	1.00	4.10
Z- value	0.02 (+)	0.96 (-)	0.44 (-)	0.28 (-)	0.05 (+)	0.95 (-)
4. Experimental condition III (Reverse spelling Task)						
Mean	0.63	0.35	0.51	0.81	0.47	0.93
SD	0.20	0.11	0.34	0.73	0.37	0.78
Range	0.67	**0.34**	0.88	2.41	1.27	1.99
Z- Value	0.88 (-)	0.04 (+)	0.68 (-)	0.28 (-)	0.23 (-)	0.65 (-)

GRAPH XVII - Mean Values of Vowels /a/, /i/ & /u/ for males and females of the smoothed amplitude perturbation quotient

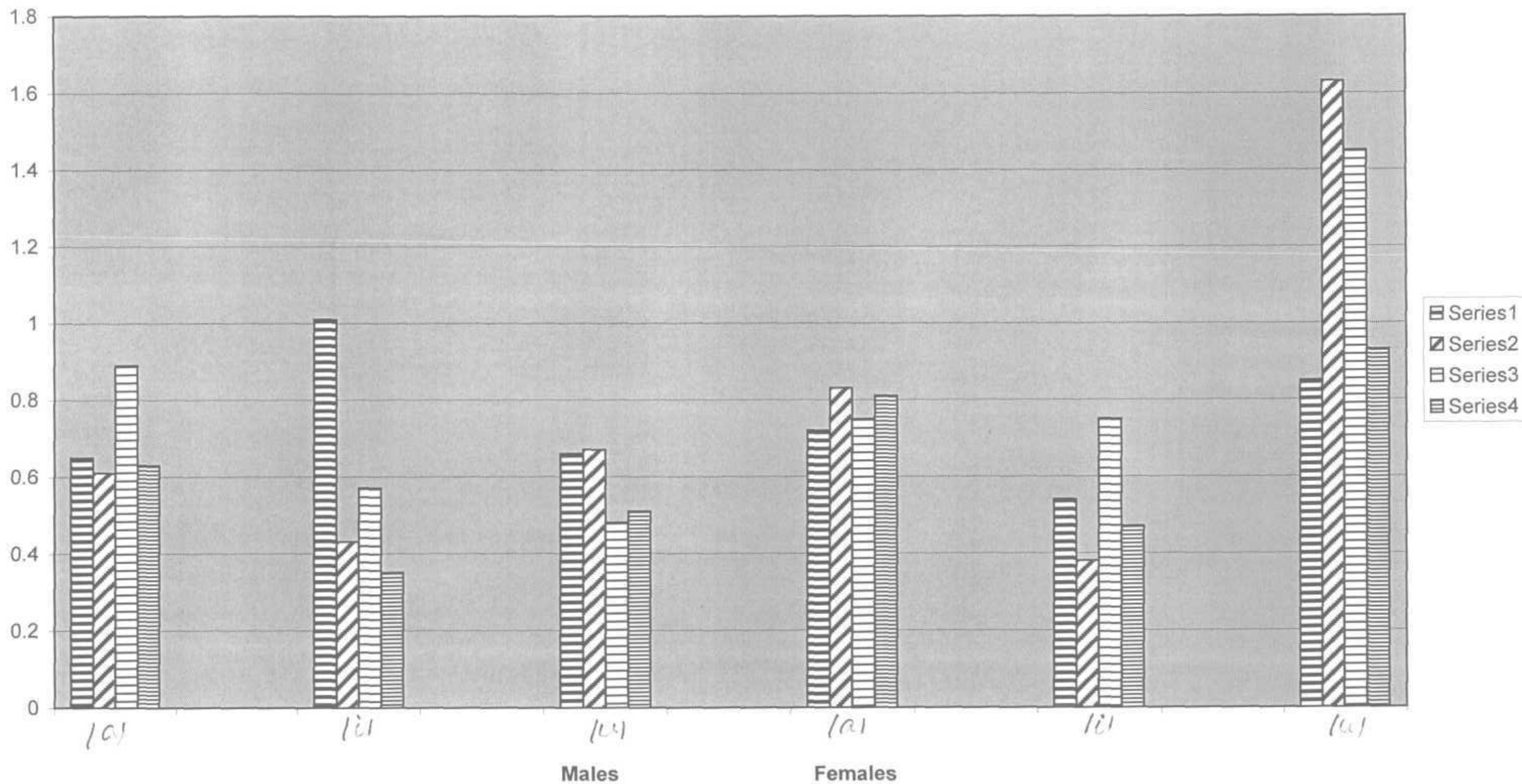
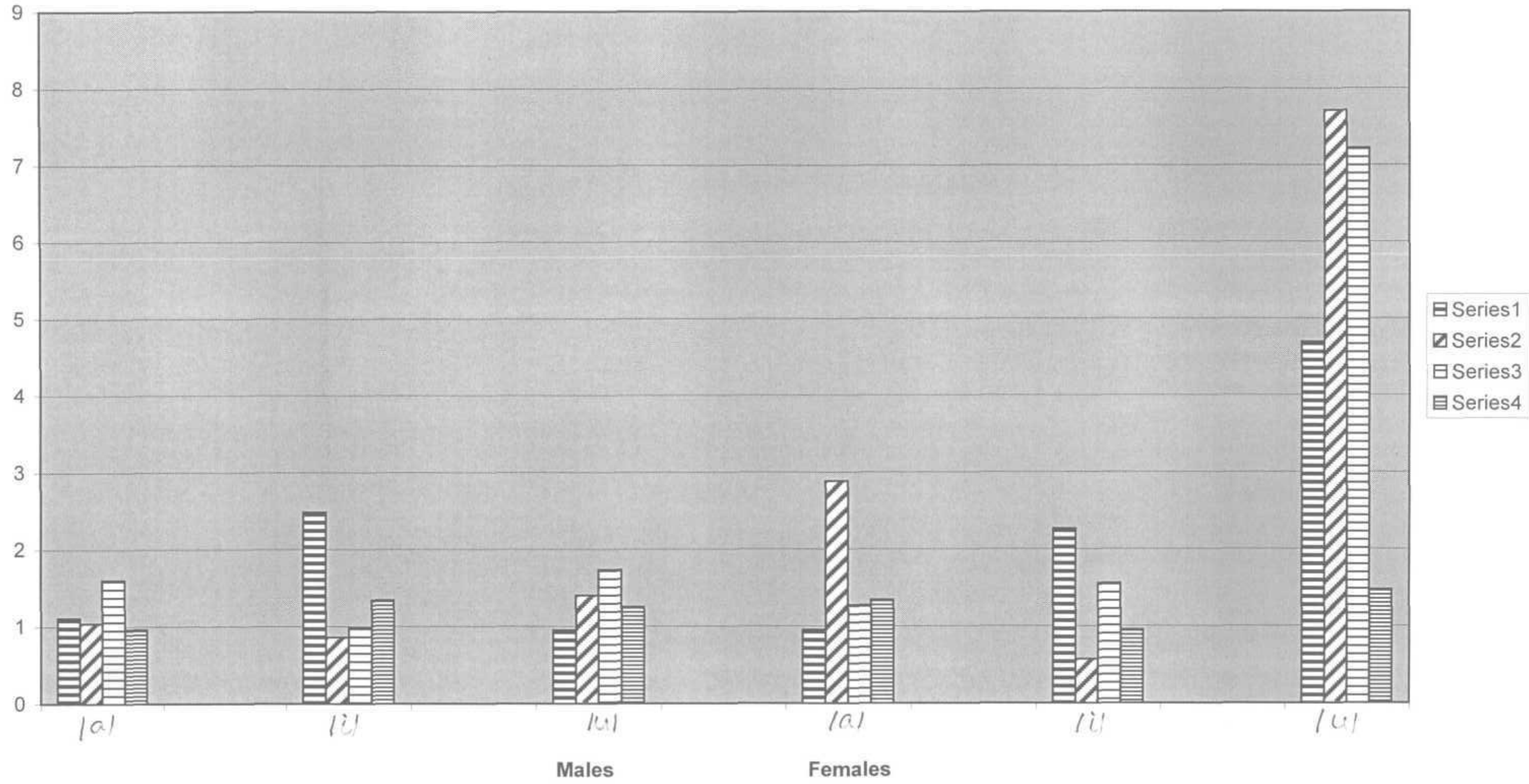


Table -XVIII:- Co-efficient of Amplitude variation (Vam) values for both males and females in the baseline and the experimental conditions.

CONDITIONS	*MALES*			*FEMALES*		
	/a/	*hi*	**/n/**	/a/	*l\l*	*Inl*
1. *Baseline Condition*						
Mean	1.11	2.48	0.95	0.95	2.26	4.69
SD	0.29	3.18	0.80	0.75	3.93	5.95
Range	0.74	8.83	1.99	2.64	11.78	16.73
2. *Experimental Condition I (Tongue Twister Task)*						
Mean	1.04	0.86	1.40	2.88	0.57	7.71
SD	0.38	0.33	1.63	5.72	0.27	14.16
Range	1.38	0.87	5.21	18.42	0.88	35.69
Z- value	0.51 (-)	0.29 (-)	0.65 (-)	0.44 (-)	0.33 (-)	0.79 (-)
3. *Experimental Condition II (Tongue Twister with DAF Task)*						
Mean	1.60	0.98	1.73	1.27	1.55	7.22
SD	0.74	0.78	2.06	1.35	0.99	12.87
Range	2.58	2.87	6.29	4.39	2.35	37.82
Z- value	0.10 (-)	0.57 (-)	0.44 (-)	0.38 (-)	0.44 (-)	0.72 (-)
4. *Experimental condition III (Reverse spelling Task)*						
Mean	0.96	1.34	1.25	1.34	0.95	1.47
SD	0.29	2.46	1.39	0.91	0.82	1.31
Range	0.82	7.98	4.82	2.88	2.28	3.70
Z- Value	0.17 (-)	0.16 (-)	0.57 (-)	0.33 (-)	0.39 (-)	0.14 (-)

GRAPH XVIII - Mean Values of Vowels /a/, /i/ & /u/ for males and females of the coefficient of amplitude variation



19. Noise to Harmonic Ratio (NHR):

This is the general evaluation of noise present in the analysed signal which is given by average ratio of the inharmonic spectral energy in the frequency range 1500-4500 Hz to the harmonic spectral energy in the frequency range 70-4500 Hz.

Table XIX gives the mean, SD and range values for the baseline and the three experimental conditions incase of both male and female subjects. The table also gives the Z-values which are obtained by comparing the respective measures of the experimental conditions with those of the baseline condition for both males and females. Significant difference, if any, is also indicated.

The table shows the mean, SD and range values in the baseline condition to be similar to the norms given by Anitha (1994). Thus indicating that there is no extra amount of noise present in the stressed condition.

Also the values in the other experimental conditions are similar to those of the baseline and no significant difference is obtained on statistical analysis for both male and female populations. Thus the task of cognitive workload do not induce any extra amount of stress than that present in the baseline condition.

20. Voice Turbulence Index (VTI) :-

VT1 mostly correlates with the turbulence caused by incomplete or loose adduction of the vocal folds. It analyses the high frequency components to extract an acoustic correlates to "breathiness".

As seen from the table, the mean, SD and range values for the baseline condition are similar to those of the normals as given by Anitha(1994), except for the phonation of /i/ by males, where higher VTI values are observed. This can be attributed to greater adduction of vocal folds under stressed condition. However, earlier studies do not report of higher VTI (Mendoza and Caraballo, 1998). Also this being only one value is not valid.

In the first experimental condition, i.e. tongue twister task, higher VTI values are observed for phonation of /a/ by both males and females. These are also statistically significant, when compared to the baseline (Z=0.01 for males, Z=0.05 for females). The values for phonation of /i/by males are significantly lower, when compared to the baseline (Z=0.08), but within normal range (Anitha, 1994).

In the second experimental condition, again higher values are observed for phonation of /a/ by males, which are also statistically significant when compared to the baseline (Z=0.01). This again indicates greater adduction of the vocal folds in this task of cognitive workload. However, this being only one value, is not valid. The VTI measures for phonation of /i/ by males is significantly lower, when compared to the baseline (Z=0.07), however within normal range (Anitha, 1994).

Again in the reverse spelling task normal values are obtained for phonation of /i/ by males, but are statistically significant (Z=0.06), when compared to baseline, because of higher values seen in the baseline condition.

However there being only one or two vowel phonations showing significant differences in each of the experimental conditions, the results of this parameter can not be generalised.

Table -XIX :- Noise to Harmonic Ratio (NHR) values for both males and females in the baseline and the experimental conditions

CONDITIONS	*MALES*			*FEMALES*		
	/a/	/i/	/u/	/a/	/i/	/u/
1. Baseline Condition						
Mean	0.17	0.25	0.12	0.14	0.12	0.11
SD	0.03	0.32	0.02	0.02	0.03	0.03
Range	0.09	1.08	0.08	0.06	0.10	0.09
2. Experimental ConditionI (Tongue Twister Task)						
Mean	0.16	0.13	0.13	0.13	0.11	0.14
SD	0.03	0.02	0.02	0.02	0.02	0.02
Range	0.12	0.05	0.08	0.07	0.08	0.09
Z- value	0.64 (-)	0.33 (-)	0.33 (-)	0.87 (-)	0.50 (-)	0.81 (-)
3. Experimental Condition II (Tongue Twister with DAF Task)						
Mean	0.18	0.17	0.12	0.14	0.14	0.12
SD	0.06	0.07	0.06	0.05	0.03	0.01
Range	0.21	0.24	0.25	0.02	0.12	0.05
Z- value	0.72 (-)	0.51 (-)	0.31 (-)	0.44 (-)	0.163 (-)	0.82 (-)
4. Experimental condition III (Reverse spelling Task)						
Mean	0.16	0.13	0.11	0.15	0.12	0.10
SD	0.02	0.01	0.06	0.03	0.02	0.03
Range	0.07	0.05	0.20	0.09	0.06	0.13
Z- Value	0.51 (-)	0.44 (-)	0.88 (-)	0.11 (-)	0.33 (-)	0.58 (-)

GRAPH XIX - Mean Values of Vowels /a/, /i/ & /u/ for males and females of the Noise to Harmonic Ratio

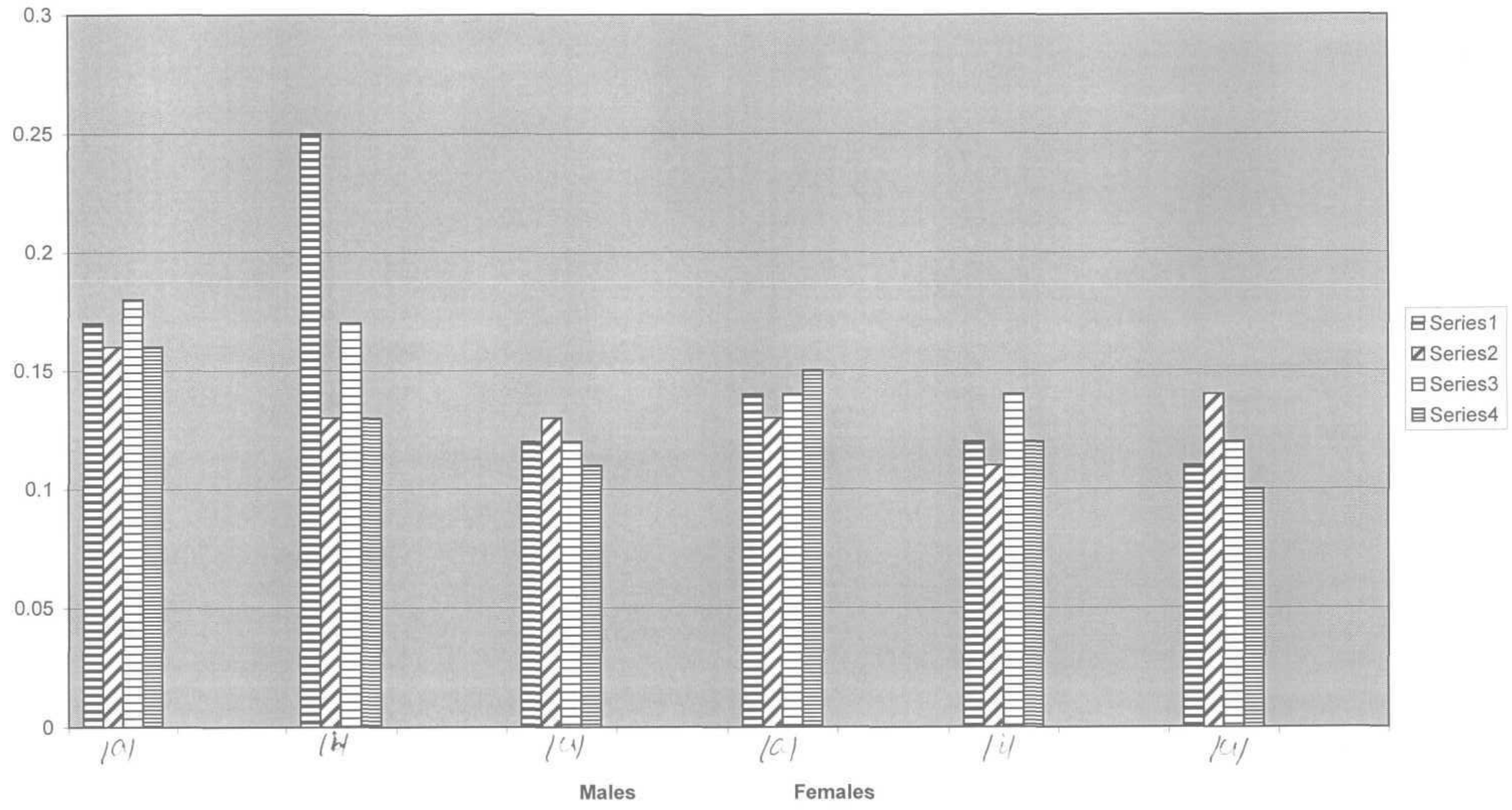
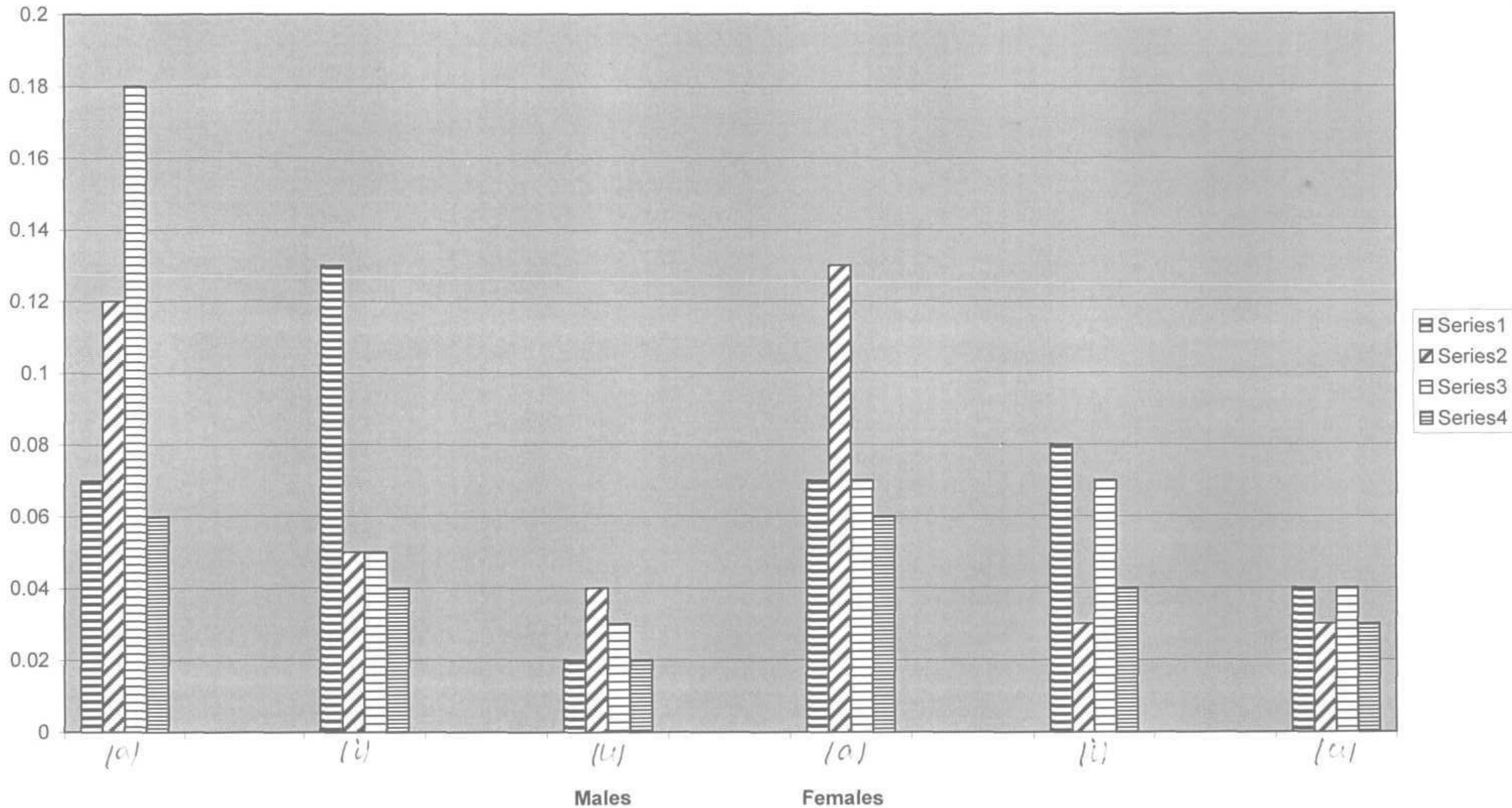


Table -XX :- Voice Turbulence Index (VTI) values for both males and females in the baseline and the experimental conditions.

CONDITIONS	*MALES*			*FEMALES*		
	/a/	/i/	**/u/**	**/a/**	/i/	/u/
1. Baseline Condition Mean SD Range	 0.07 0.02 0.06	 0.13 0.22 0.73	 0.02 0.06 0.02	 0.07 0.03 0.10	 0.08 0.11 0.36	 0.04 0.04 0.16
2. Experimental Condition I (Tongue Twister Task) Mean SD Range Z- value	 0.12 0.20 0.65 0.01 (+)	 0.05 0.02 0.07 0.08 (-)	 0.04 0.07 0.24 0.72 (-)	 0.13 0.19 0.63 0.05 (+)	 0.03 0.01 0.04 0.12 (-)	 0.03 0.01 0.05 0.87 (-)
3. Experimental Condition II (Tongue Twister with DAF Task) Mean SD Range Z- value	 0.18 0.25 0.73 0.01 (+)	 0.05 0.02 0.07 0.07 (-)	 0.03 0.01 0.05 0.11 (-)	 0.07 0.02 0.07 0.38 (-)	 0.07 0.04 0.15 0.20 (-)	 0.04 0.01 0.03 0.31 (-)
4. Experimental condition III (Reverse spelling Task) Mean SD Range Z- Value	 0.06 0.02 0.09 0.88 (-)	 0.04 0.01 0.03 0.06 (+)	 0.02 0.01 0.05 0.72 (-)	 0.06 0.03 0.10 0.17 (-)	 0.04 0.04 0.14 0.17 (-)	 0.03 0.01 0.06 0.31 (-)

GRAPH XX - Mean Values of Vowels /a/, /i/ & /u/ for males and females of the voice turbulence index



21) Soft phonation Index (SPI)

It is the average ratio of the lower frequency harmonic energy in the range of 70-1600 Hz to the higher frequency harmonic energy in the range 1600-4500 Hz.

The mean, SD and range for SPI for the baseline condition are presented in Table XXI for both male and female subjectsThe Z-values given are obtained by comparing the measures of the three experimental conditions with those of the baseline. These values are given for the experimental conditions and the significant difference with the baseline is also indicated.

The mean, SD and range values in the baseline condition are similar to those obtained for the normal limits data by Anitha (1994).These findings thus do not support the results of other studies, where increased SPI was found under stressed conditions (Mendoza and Caraballo,1998).

The table shows similar mean, SD and range values for both males and females in the second experimental and the baseline condition. Also statistical analysis revealed no significant difference between the two conditions.

The mean and SD values for the phonation of |u| by male and phonation of all the three vowels |a|, |i|, |u| by females is slightly lower when compared to the baseline condition in the second experimental condition i.e. Tongue twister with DAF task.

Also the statistical analysis revealed significant difference between the baseline and reading of the tongue twister with DAF condition. This was observed for SPI measurement for phonation of/u/ in case of male subjects (Z=0.01) and phonation of all three vowels by female subjects. (Z=0.03, for /a/; Z-0.02 for /i/; and Z=0.01 for /u/). These lower values can be attributed to the "pressed" phonation for these vowels. However, this is contrary to the findings of earlier studies,where, increased SPI values were observed for cognitive workload tasks (Mendoza and Caraballo,1998).

The mean, SD and range values in the third experimental condition are found to be similar to those in the baseline condition. Also no significant difference was observed between baseline and condition of spelling the English word in reverse order for both males and females statistically.Thus no change in the SPI parameter is observed for this condition of cognitive workload when compared to the baseline.

22) Frequency Tremor Intensity Index (FTRI)

It is defined as the average ratio of the frequency magnitude of the most intensive low frequency modulating component to the total frequency magnitude of the analysed voice signal.

The mean, SD and range are presented in table XXII for baseline and the three experimental conditions in case of both male and female subjectsThe table also gives the Z-scores when the three experimental conditions are compared with the baseline. Any significant difference is also indicated.

The mean, SD and range values are slightly higher when compared to the normal values as given by Anitha (1994), for both male and female subjects in the baseline condition. This difference can be due to the inability to maintain constant pitch in stressed condition.

Table -XXI:- Soft Phonation Index (SPI) values for both males and females in the baseline and the experimental conditions.

CONDITIONS	*MALES*			*FEMALES*		
	/a/	/i/	/u/	/a/	/i/	/u/
1. Baseline Condition						
Mean	5.13	9.59	11.73	4.37	9.06	8.62
SD	1.02	3.27	2.64	1.76	3.34	2.55
Range	2.95	10.09	8.14	4.99	11.44	8.66
2. Experimental Condition I (Tongue Twister Task)						
Mean	5.16	9.63	10.33	4.53	8.27	7.73
SD	1.27	4.19	3.37	2.09	2.99	3.18
Range	4.33	12.58	11.67	7.30	7.34	8.71
Z- value	0.65 (-)	0.79 (-)	0.44 (-)	0.79 (-)	0.24 (-)	0.33 (-)
3. Experimental Condition ***II (Tongue Twister with DAF Task)***						
Mean	5.15	9.77	7.61	3.27	5.63	6.57
SD	1.13	2.71	3.10	0.64	3.76	1.92
Range	3.97	8.25	11.14	2.10	11.97	6.69
Z- value	0.64 (-)	0.65 (-)	0.01 (+)	0.03 (+)	0.02 (+)	0.01 (+)
4. Experimental condition III (Reverse spelling Task)						
Mean	4.88	9.55	10.12	4.55	9.15	8.84
SD	1.04	3.19	5.27	2.12	3.50	4.77
Range	3.28	9.56	17.87	7.18	10.53	16.89
Z- Value	0.33 (-)	0.72 (-)	0.33 (-)	0.72 (-)	0.88 (-)	0.79 (-)

GRAPH XXI - Mean Values of Vowels /a/, /i/ & /u/ for males and females of the soft phonation index

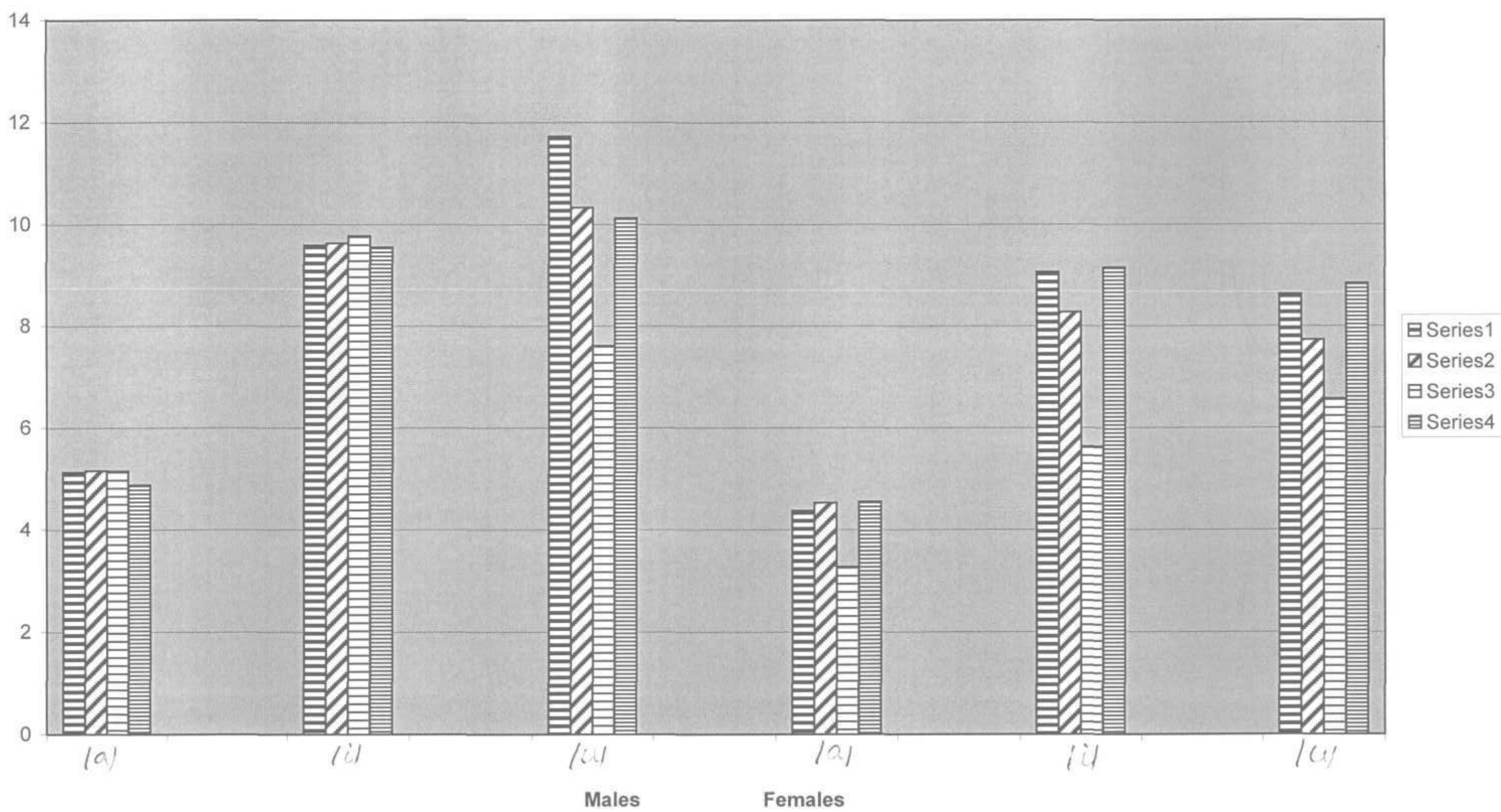
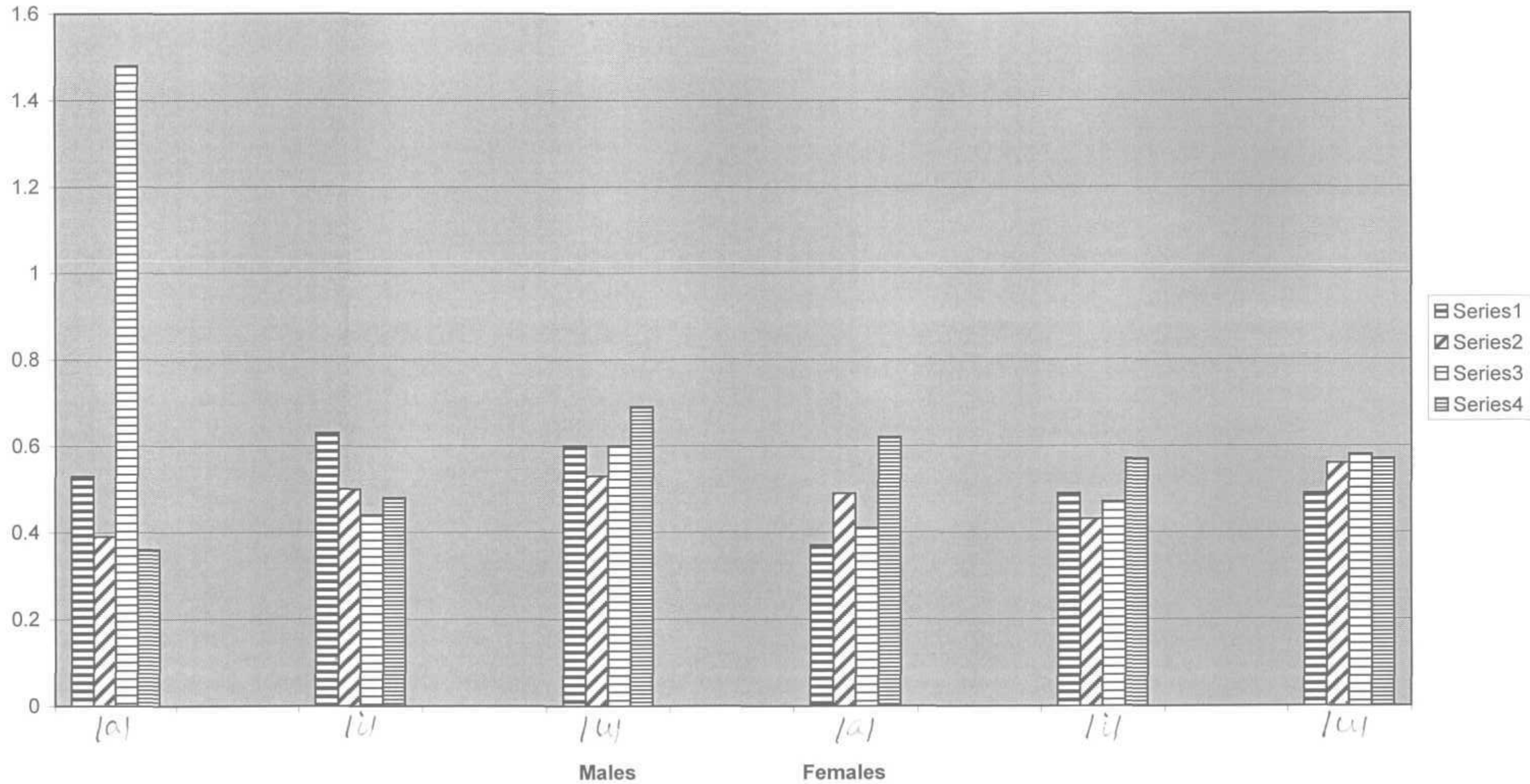


Table -XXII:- Frequency Tremor Intensity Index (FTRI) values for both males and females in the baseline and the experimental conditions

CONDITIONS	*MALES*			*FEMALES*		
	/a/	/i/	/u/	/a/	/i/	/u/
1. *Baseline Condition*						
Mean	0.53	0.63	0.60	0.37	0.49	0.49
SD	0.25	0.63	0.64	0.23	0.44	0.37
Range	0.82	1.96	2.10	0.67	**1.61**	1.05
2. *Experimental Condition I (Tongue Twister Task)*						
Mean	0.39	0.50	0.53	0.49	0.43	0.56
SD	0.32	0.14	0.38	0.42	0.57	0.56
Range	1.03	0.49	1.22	1.38	1.93	1.86
Z- value	0.28 (-)	0.57 (-)	0.96 (-)	0.20 (-)	0.33 (-)	0.28 (-)
3. *Experimental Condition II (Tongue Twister with DAF Task)*						
Mean	**1.48**	0.44	0.60	0.41	0.47	0.58
SD	**2.78**	0.27	0.52	0.43	0.42	0.37
Range	9.06	0.89	1.68	7.59	1.37	1.27
Z- value	0.05 (+)	0.80 (-)	0.96 (-)	0.72 (-)	0.79 (-)	0.38 (-)
4. *Experimental condition III (Reverse spelling Task)*						
Mean	**0.36**	**0.48**	0.69	0.62	0.57	0.57
SD	0.26	0.29	0.43	0.54	0.62	0.53
Range	0.82	0.88	1.26	1.69	2.06	1.79
Z- Value	0.20 (-)	0.96 (-)	0.51 (-)	0.05 (+)	0.58 (-)	0.72 (-)

GRAPH XXII - Mean Values of Vowels /a/, /i/ & /u/ for males and females of the frequency tremor intensity index



The table shows the mean, SD and range values in the first and second experimental conditions to be similar to those of the baseline condition. Also no significant difference was found on the statistical analysis when the baseline and these experimental conditions were compared.

As seen from the table, the mean, SD and range values are slightly higher for females in the third experimental condition when compared to those of the baseline. Also statistical analysis revealed significant difference between baseline and this experimental condition for the phonation of /a/ by females (z=0.05). No other significant difference was found. However, this being only one value showing a significant difference is not valid

23. Amplitude Tremor Intensity Index (ATRI):

This gives the average ratio of the amplitude of the most intense low frequency amplitude modulating component to the total amplitude of the analysed voice signal.

Table XXIII gives the mean, SD and range values for the baseline and the three experimental conditions for both males and females. The table also shows the Z-values ,which are obtained when the experimental conditions are compared with the baseline condition. Significant difference , if any, is also indicated by +/- sign, referring presence and absence of difference respectively.

As seen from the table, the mean, SD and range values for the three experimental conditions are similar to those in the baseline. Also no significant difference is observed when the values in the experimental conditions are compared with those in the baseline for both male and female populations.

The mean, SD and range values are also found to be within normal limits for the baseline condition. Thus, the condition of induced stress does not produce any change in the amplitude of voice. The task of tongue twister with DAF also did not show any significant change in voice with respect to this parameter.

24. Degree of voice Breaks (DVB):

It is defined as ratio of the total length of the areas represented voice breaks to the time of complete voice sample. It measures the ability of the voice to sustain uninterrupted voicing.

The table XXIV shows mean, SD and range for the baseline and the three experimental conditions for both males and females. The table also shows the Z values and significant difference if any, between the baseline and the three experimental conditions of cognitive workload.

The mean, SD and range values for the phonation of /i/ by male subjects is slightly higher when compared to the normative data given by Anitha, 1994 in the baseline condition.

The mean, SD and range values are found to be within the normal range and also no significant difference is thus observed for both males and females in the first experimental condition.

Table -XXIII:- Amplitude Tremor Intensity Index (ATRI) values for both males and females in the baseline and the experimental conditions

CONDITIONS	*MALES*			*FEMALES*		
	/a/	/i/	/u/	/a/	/i/	/u/
1. Baseline Condition						
Mean SD Range	0.32 0.17 0.59	0.34 0.29 1.04	0.24 0.19 0.68	0.30 0.11 0.35	0.46 0.79 2.55	0.30 0.31 1.05
2. Experimental Condition I (Tongue Twister Task)						
Mean SD Range Z- value	0.42 0.21 0.64 0.17 (-)	0.33 0.29 0.99 0.72 (-)	0.32 0.19 0.63 0.28 (-)	0.35 0.42 1.46 0.68 (-)	0.16 0.06 0.21 0.72 (-)	1.78 4.13 3.19 0.51 (-)
3. Experimental Condition II (Tongue Twister with DAF Task)						
Mean SD Range Z- value	0.52 0.32 1.15 0.02 (+)	0.24 0.08 0.27 0.44 (-)	0.47 0.59 1.80 0.59 (-)	0.52 0.89 3.02 0.33 (-)	0.38 0.23 0.87 0.57 (-)	0.47 0.73 2.33 0.95 (-)
4. Experimental condition III (Reverse spelling Task)						
Mean SD Range Z- Value	0.25 0.15 0.44 0.28 (-)	0.24 0.14 0.36 0.13 (-)	0.38 0.31 1.09 0.28 (-)	0.36 0.26 0.73 0.57 (-)	0.16 0.12 0.41 0.33 (-)	0.52 0.48 1.32 0.39 (-)

GRAPH XXIII - Mean Values of Vowels /a/, /i/ & /u/ for males and females of the amplitude tremor intensity index

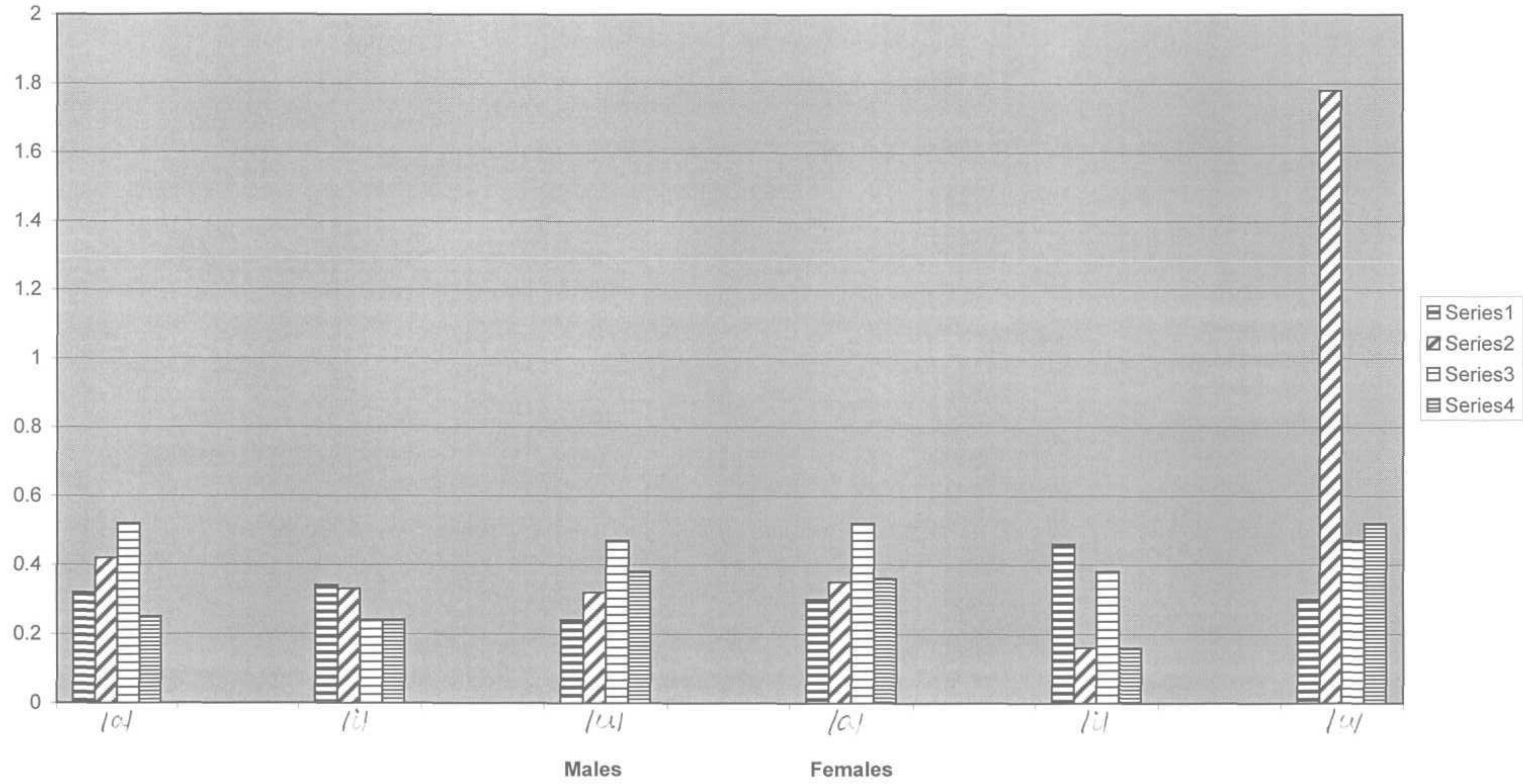
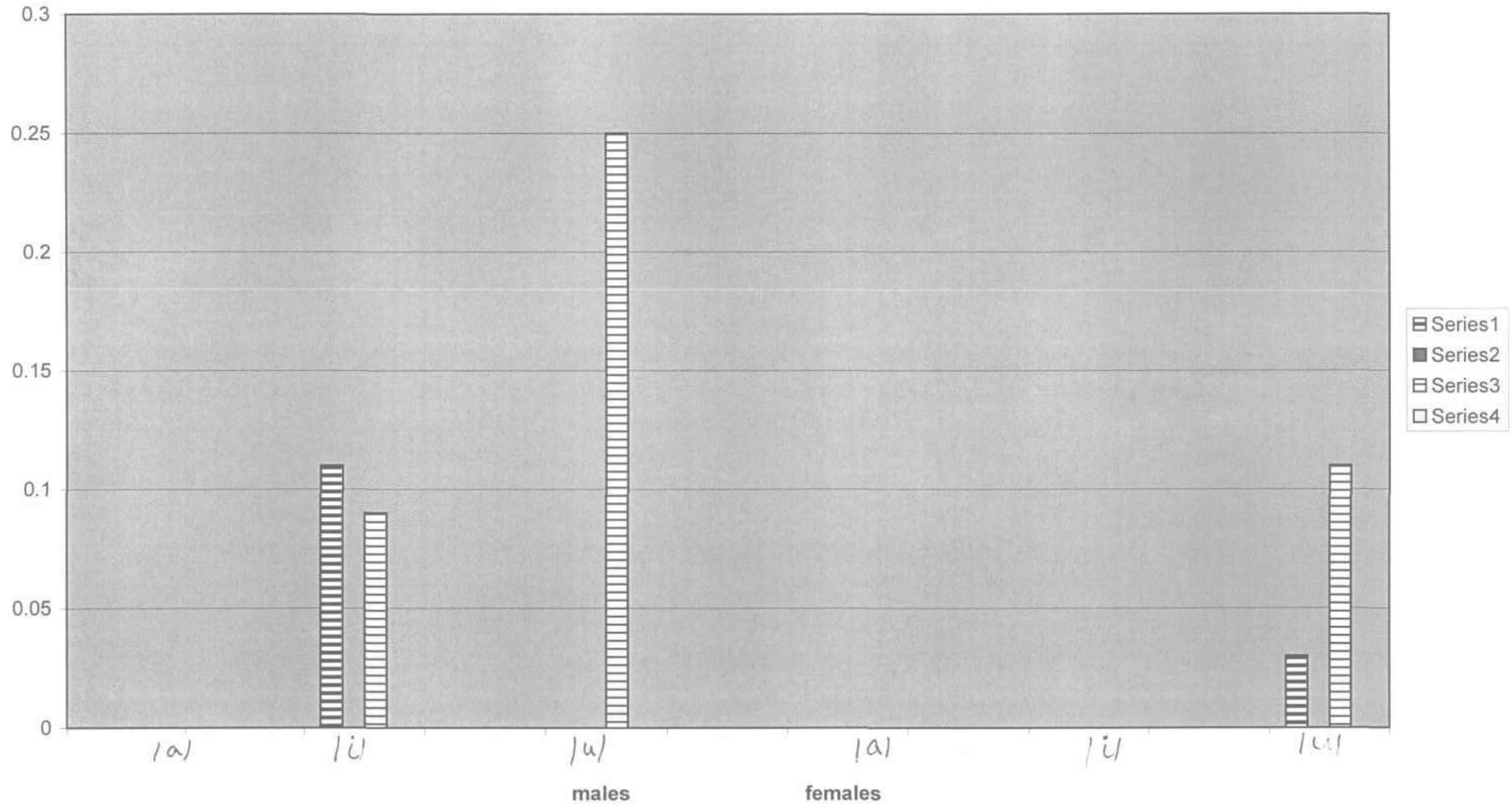


Table -XXIV :- Degree of Voice Breaks (DVB) values for both males and females in the baseline and the experimental conditions.

CONDITIONS	***MALES***			*FEMALES*		
	/a/	/i/	/u/	/a/	/i/	/u/
1. Baseline Condition						
Mean	0.00	0.11	0.00	0.00	0.00	0.03
SD	0.00	0.36	0.00	0.00	0.00	0.09
Range	0.00	1.13	0.00	0.00	0.00	0.28
2. Experimental Condition I ***(Tongue Twister Task)***						
Mean	0.00	0.00	0.00	0.00	0.00	0.00
SD	0.00	0.00	0.00	0.00	0.00	0.00
Range	0.00	0.00	0.00	0.00	0.00	0.00
Z- value	1.00 (-)	0.32 (-)	1.00 (-)	1.00 (-)	1.00 (-)	0.32 (-)
3. Experimental Condition ***II (Tongue Twister with DAF Task)***						
Mean	0.00	0.09	0.25	0.00	0.00	0.11
SD	0.00	0.29	0.78	0.00	0.00	0.33
Range	0.00	0.95	2.48	0.00	0.00	1.05
Z- value	1.00 (-)	0.66 (-)	0.32 (-)	1.00 (-)	1.00 (-)	0.65 (-)
4. Experimental condition III (Reverse spelling Task)						
Mean	0.00	0.00	0.00	0.00	0.00	0.00
SD	0.00	0.00	0.00	0.00	0.00	0.00
Range	0.00	0.00	0.00	0.00	0.00	0.00
Z- Value	1.00 (-)	0.32 (-)	1.00 (-)	1.00 (-)	1.00 (-)	0.32 (-)

In the second experimental condition i.e. the tongue twister with DAF task, the mean, SD and range values are higher for phonation of *lul* by both males and females, when compared to the baseline condition. However statistical analysis does not reveal any significant difference for both the populations. The higher values can be

GRAPH XXIV- Mean values of vowels /a/,/i/ &/u/ for males and females of the Degree of Voice Breaks



attributed to irregular vibrations of the vocal folds caused due to stress (Scherer, 1986). However, this change in physiology is not found to be significant.

The values are similar to those of the baseline and also no significant difference was observed for both males and females on statistical analysis in the third experimental condition i.e. reverse spelling task.

25. Degree of sub- harmonic breaks (DSH)

It is defined as the relative evaluation of the sub-harmonic of Fo component in the voice sample .

The mean, SD and range for this parameter are given in Table XXV for the baseline and three experimental conditions for both male and female subjects.The table also gives the Z- values which are obtained by comparing the respective measures of the experimental conditions with those of the baseline condition for both males and females. Significant difference, if any, is also indicated.

The mean and SD values are slightly higher for males when compared to the normal values given by Anitha, 1994 for males. No such difference is observed for females in the baseline condition. This increase in the degree of breaks can be because of the inability to maintain a constant pitch while phonation.

The mean and SD values in the first experimental task for the phonation of /u/ by male subjects and phonation of /a/ and /u/ by female subjects is slightly higher when compared to the baseline. However, no significant difference was found between the baseline and this experimental condition for males and females on statistical analysis.

The mean and SD values in the second experimental task are higher for phonation of /a/ by males when compared to the baseline condition. However, statistical analysis revealed no significant difference between baseline and this experimental condition for both males and females.

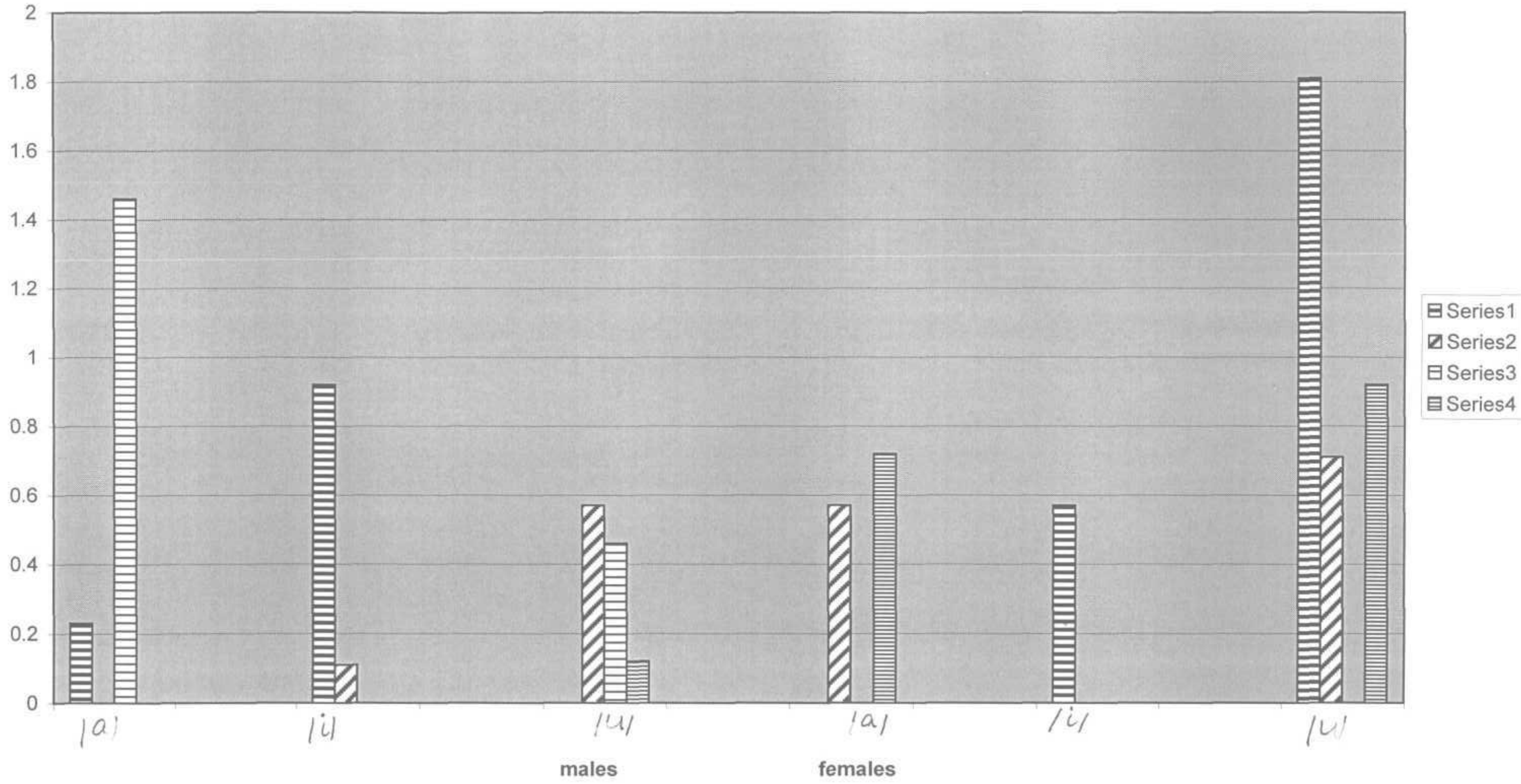
The mean and SD values in the third experimental condition are higher for phonation of /a/ and /u/*l* by females for this experimental condition. However, statistical analysis revealed no significant difference between baseline and the condition of spelling of the English word in reverse order task for both males and females.

The results may be discussed as follows. Since sub-harmonic component is the relative evaluation of sub-harmonic to F_o component in the voice sample and as sub-harmonic components increases when there is double or triple pitch periods which replace the fundamental in certain segments over the analysis length. Thus, in stressed conditions there is change in Fo because of the inability to maintain a constant pitch. This is even present for the experimental conditions of cognitive workload.

Table -XXV :- Degree of Sub - Harmonic Break (DSH) values for both males and females in the baseline and the experimental conditions.

CONDITIONS	*MALES*			*FEMALES*		
	/a/	**/i/**	**/u/**	/a/	/i/	/u/
1. Baseline Condition						
Mean	0.23	0.92	0.00	0.00	0.57	1.81
SD	0.73	2.53	0.00	0.00	1.82	3.65
Range	2.30	8.05	0.00	0.00	5.75	11.25
2. *Experimental Condition I (Tongue Twister Task)*						
Mean	0.00	0.11	0.57	0.57	0.00	0.71
SD	0.00	0.36	1.82	1.24	0.00	1.82
Range	0.00	1.15	5.75	3.45	0.00	5.75
Z- value	0.32 (-)	0.18 (-)	0.32 (-)	0.18 (-)	0.32 (-)	0.28 (-)
3. Experimental Condition II (Tongue Twister with DAF Task)						
Mean	1.46	0.00	0.46	0.00	0.00	0.00
SD	3.21	0.00	1.47	0.00	0.00	0.00
Range	9.20	0.00	4.65	0.00	0.00	0.00
Z- value	0.28 (-)	0.18 (-)	0.32 (-)	1.00 (-)	0.32 (-)	0.11 (-)
4. Experimental condition 111 (Reverse spelling Task)						
Mean	0.00	0.00	0.12	0.72	0.00	0.92
SD	0.00	0.00	0.39	1.28	0.00	2.22
Range	0.00	0.00	1.25	3.45	0.00	6.90
Z- Value	0.32 (-)	0.18 (-)	0.32 (-)	0.12 (-)	0.32 (-)	0.41 (-)

GRAPH XXV- Mean values of vowels /a/, /i/ &/u/ for males and females of the Degree of sub-harmonic Breakes



26. Degree of Voiceless (DUV):

DUV is the estimated relative evaluation of non-harmonic areas in the voice sample.

Table XXVI gives the mean, SD and range values for the baseline and the three experimental conditions for both males and females. The Z-values given are obtained by comparing the measures of the three experimental conditions with those of the baseline. These values are given for the experimental conditions and the significant difference with the baseline is also indicated.

The mean and SD values are higher when compared to those of the normal subjects (Anitha, 1944) for the phonation of /i/*l* and /u/ for both male and female subjects, in the baseline condition. This can be attributed to subjects inability to maintain a constant pitch and uninterrupted voicing due to the presence of stress in this condition.

The mean and SD values for the phonation of /u/ for males and phonation of /a/ for females are higher in the tongue twister task when compared to the normal values (Anitha, 1994). However, statistical analysis revealed no significant difference between baseline and first experimental condition for both males and females.

Higher mean and SD values are also observed for the phonation of/a/ by male subjects when compared to the normal subjects (Anitha, 1994) for the second experimental condition. Statistical analysis revealed no significant difference for the baseline and this experimental condition for both males and females.

As seen from the table, the mean and SD values in the third experimental condition are higher for the prolongation of vowels by male subjects when compared to the normal values given by Anitha (1994). No significant difference was however, found between the baseline and the experimental condition of spelling the English word in reverse order for this parameter in both male and female subjects.

Thus, though higher values are observed for the phonation of vowels in the baseline and the experimental conditions, they do not show any significant difference. The values in the experimental conditions are similar to those in the baseline, thus indicating that the tasks of cognitive work load do not produce any excess amount of stress than that present in the baseline condition. However, the presence of stress does cause an inability to maintain a constant pitch and uninterrupted voicing due to changes in the physiology of the vocal folds (Scherer, 1986).

27. **Number of Voice Breaks (NVB)**:

NVB is the number of times the fundamental period was interrupted during the voice sample. The mean, SD and range for this parameter are given in table XXVII for the baseline and the three experimental conditions in both male and female subjects. The table also gives the Z-scores when the three experimental conditions are compared with the baseline. Any significant difference is also indicated.

Table -XXVI:- Degree of Voiceless (DUV) values for both males and females in the baseline and the experimental conditions

CONDITIONS	*MALES*			*FEMALES*		
	/a/	/i/	/u/	/a/	/i/	/u/
1. Baseline Condition						
Mean	0.00	0.34	0.59	0.00	0.12	0.59
SD	0.00	1.09	1.88	0.00	0.37	1.51
Range	0.00	3.45	5.95	0.00	1.18	4.76
2. Experimental Condition I (Tongue Twister Task)						
Mean	0.11	0.00	0.59	0.68	0.00	0.00
SD	0.38	0.00	1.88	2.18	0.00	0.00
Range	1.15	0.00	5.95	6.90	0.00	0.00
Z- value	0.32 (-)	0.32 (-)	1.00 (-)	0.32 (-)	0.32 (-)	0.18 (-)
3. Experimental Condition II (Tongue Twister with DAF Task)						
Mean	1.61	0.11	0.11	0.00	0.00	0.47
SD	5.08	0.36	0.36	0.00	0.00	1.51
Range	16.09	1.15	1.15	0.00	0.00	4.76
Z- value	0.32 (-)	0.32 (-)	0.32 (-)	1.00 (-)	0.32 (-)	0.78 (-)
4. Experimental condition III (Reverse spelling Task)						
Mean	0.22	0.12	0.80	0.00	0.00	0.00
SD	0.72	0.38	2.54	0.00	0.00	0.00
Range	2.30	1.22	8.05	0.00	0.00	0.00
Z- Value	0.32 (-)	0.65 (-)	0.32 (-)	1.00 (-)	0.32 (-)	0.18 (-)

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GRAPH XXVI- Mean values of vowels /a/,/i/ &/u/ for males and females of the Degree of Voiceless

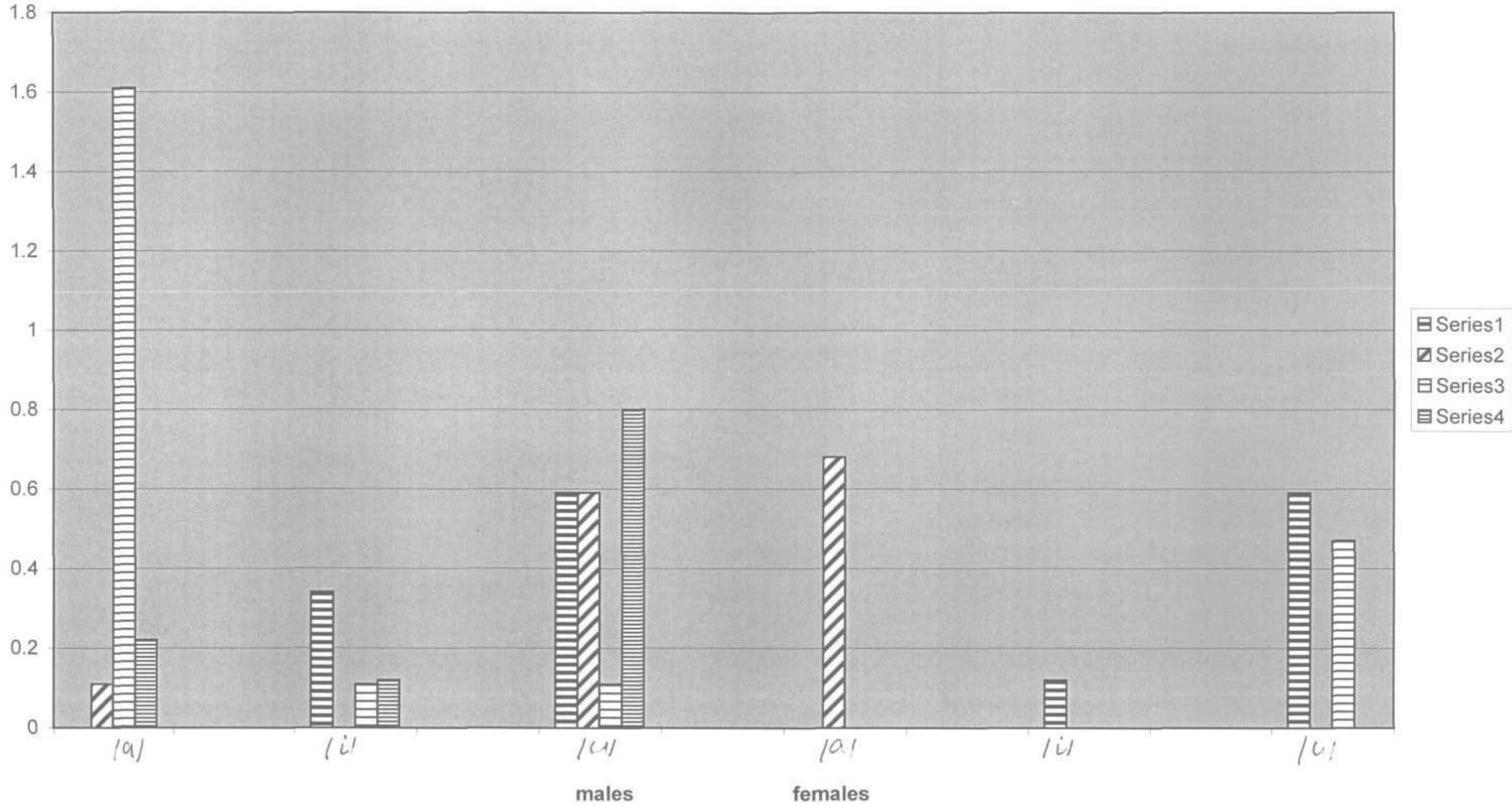
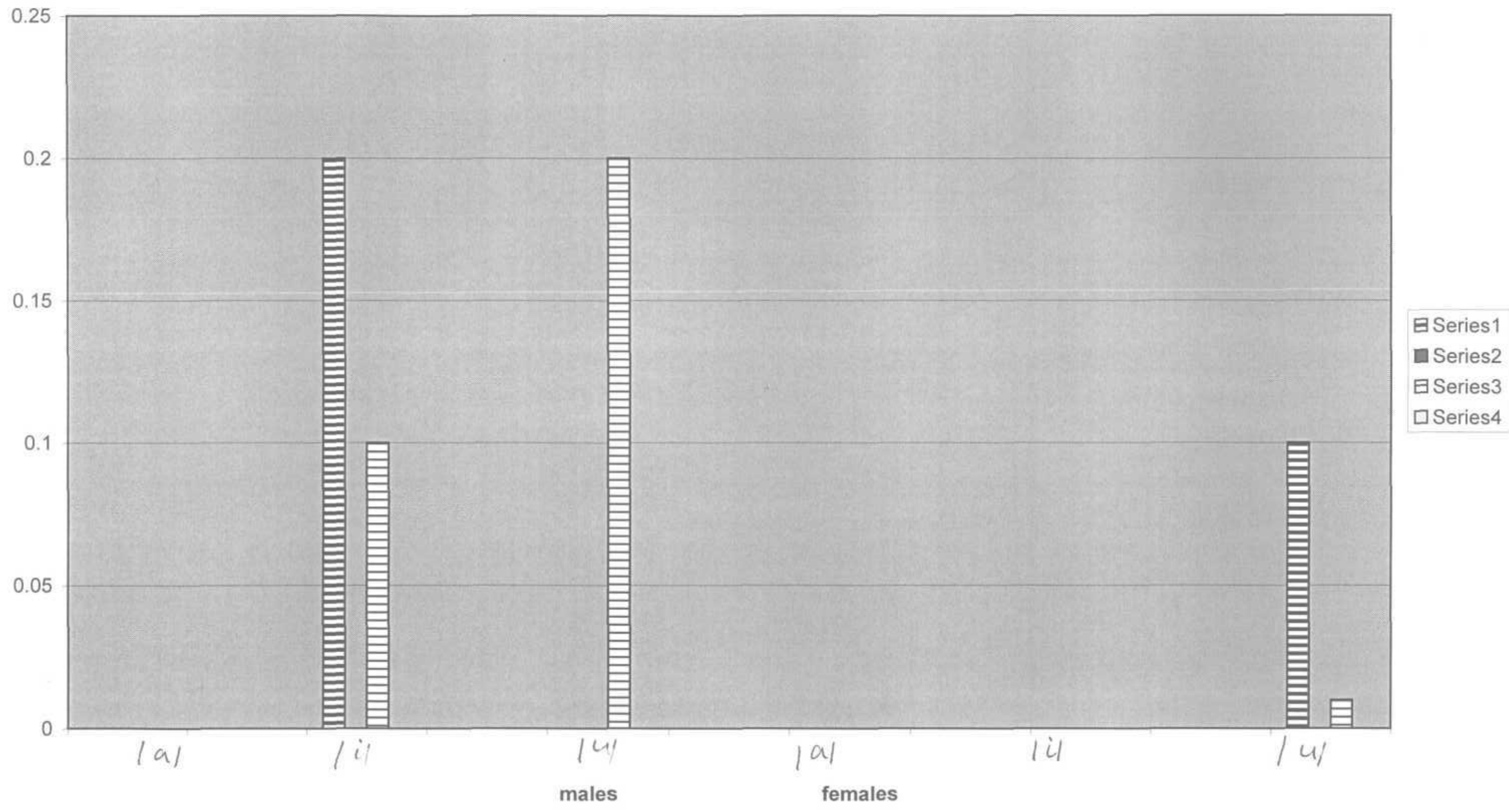


Table -XXVII:- Number of Voice Breakes (NVB) values for both males and females in the baseline and the experimental conditions.

CONDITIONS	*MALES*			***FEMALES***		
	/a/	***/i/***	/u/	/a/	***/i/***	*/u/*
L Baseline Condition						
Mean	0.00	0.20	0.00	0.00	0.00	0.10
SD	0.00	0.63	0.00	0.00	0.00	0.32
Range	0.00	2.00	0.00	0.00	0.00	1.00
2. Experimental Condition I (Tongue Twister Task)						
Mean	0.00	0.00	0.00	0.00	0.00	0.00
SD	0.00	0.00	0.00	0.00	0.00	0.00
Range	0.00	0.00	0.00	0.00	0.00	0.00
Z- value	1.00 (-)	0.32 (-)	1.00 (-)	1.00 (-)	1.00 (-)	0.32 (-)
3. Experimental Condition II (Tongue Twister with DAF Task)						
Mean	0.00	0.10	0.20	0.00	0.00	0.01
SD	0.00	0.32	0.63	0.00	0.00	0.32
Range	0.00	1.00	2.00	0.00	0.00	1.00
Z- value	1.00 (-)	0.66 (-)	0.32 (-)	1.00 (-)	1.00 (-)	1.00 (-)
4. Experimental condition III (Reverse spelling Task)						
Mean	0.00	0.00	0.00	0.00	0.00	0.00
SD	0.00	0.00	0.00	0.00	0.00	0.00
Range	0.00	0.00	0.00	0.00	0.00	0.00
Z- Value	1.00 (-)	0.32 (-)	1.00 (-)	1.00 (-)	1.00 (-)	0.32 (-)

The mean and SD values are found to be within the normal limits for both male and female subjects, in the baseline condition, norms as given by Anitha, 1994.

GRAPH XXVII- M ean values of vowels /a/,/i/ & /u/ for males and females of the Number of voice breakes



As seen from the table, the mean, SD and range values in the three experimental conditions are similar to those in the baseline. Also no significant difference was revealed on statistical analysis for both male and female populations. Thus, the tasks of cognitive workload do not produce excess amount of voice breaks.

28 Number of sub-Harmonic Breaks(NSH)

Table XXVIII gives the mean, SD and range values for the baseline and the three experimental conditions in both male and female subjects. The table also shows the Z-values which are obtained when the experimental conditions were compared with the baseline. Significant difference, if any, is also indicated by +/- sign, referring presence or absence of difference respectively.

As seen from the Table, the mean and SD values for the phonation of | i | by male subjects and for the phonation of | u | by female subjects are higher when compared to the normal limits values as given by Anitha (1994) for the baseline condition.

From the table it can be inferred that the mean and SD values for the phonation of |u| by males and phonation of |a| and |u| by females is higher when compared to those of the baseline condition in the first experimental tasks. However no significant difference was observed for both male and female subjects. These higher values can be attributed to irregular vibratory pattern of the vocal folds, in the stressed condition.

As seen from the Table, in the second experimental condition higher mean and SD values are observed for phonation of/a/ by the male subject when compared to those of the baseline condition. However statistical analysis between the baseline and this experimental condition did not show any significant difference for both male and female subjects. The higher values are due to irregular vibratory patterns which result in more than one frequency of vibration at a given instance, leading to increase in NSH values.

No significant difference is observed between the baseline and third experimental condition for both males and females.

29. Number of unvoiced segments(NUV)

NUV measures the ability of the voice to sustain uninterrupted voicing. Table XXIX gives the mean, SD and range values for the baseline and the three experimental conditions in both male and female subjects. The table also shows the Z-values and the significant difference if any, between the baseline and the three experimental conditions of cognitive workload.

The mean and SD values given in the table for the baseline condition are similar to those given for normals by Anitha 1994. Thus we can say that stressed condition do not cause any interrupted voicing and the parameter of NUV does not differentiate between the stressed and the unstressed conditions.

Similarly, in the experimental conditions of cognitive workload the mean and SD values are similar to those of the baseline for both males and females Also, no significant difference was found on statistical analysis.

Table -XXVIH :- Number of Sub-Harmonic break (NSH) values for both males and females in the baseline and the experimental conditions.

CONDITIONS	*MALES*			*FEMALES*		
	/a/	/i/	/u/	/a/	/i/	/u/
1. Baseline Condition						
Mean	0.20	0.80	0.00	0.00	0.50	**1.50**
SD	0.63	2.20	0.00	0.00	1.56	**2.95**
Range	2.00	7.00	0.00	0.00	5.00	9.00
2. Experimental Condition I (Tongue Twister Task)						
Mean	0.00	0.10	0.50	0.50	0.00	0.60
SD	0.00	0.32	1.58	1.08	0.00	1.58
Range	0.00	1.00	5.00	3.00	0.00	5.00
Z- value	0.32 (-)	0.18 (-)	0.11 (-)	0.18 (-)	0.32 (-)	0.28 (-)
3. Experimental Condition II (Tongue Twister with DAF Task)						
Mean	1.20	0.00	0.40	0.00	0.00	0.00
SD	2.70	0.00	1.26	0.00	0.00	0.00
Range	8.00	0.00	4.00	0.00	0.00	0.00
Z- value	0.28 (-)	0.18 (-)	0.32 (-)	1.00 (-)	0.32 (-)	0.11 (-)
4. Experimental condition III (Reverse spelling Task)						
Mean	0.00	0.00	0.10	0.60	0.00	0.80
SD	0.00	0.00	0.32	1.07	0.00	1.93
Range	0.00	0.00	1.00	3.00	0.00	6.00
Z- Value	0.32 (-)	0.18 (-)	0.32 (-)	0.11 (-)	0.32 (-)	0.41 (-)

GRAPH XXVIII- Mean values of vowels /a/, /i/ &/u/ for males and females of the Number of sub-harmonic Breakes

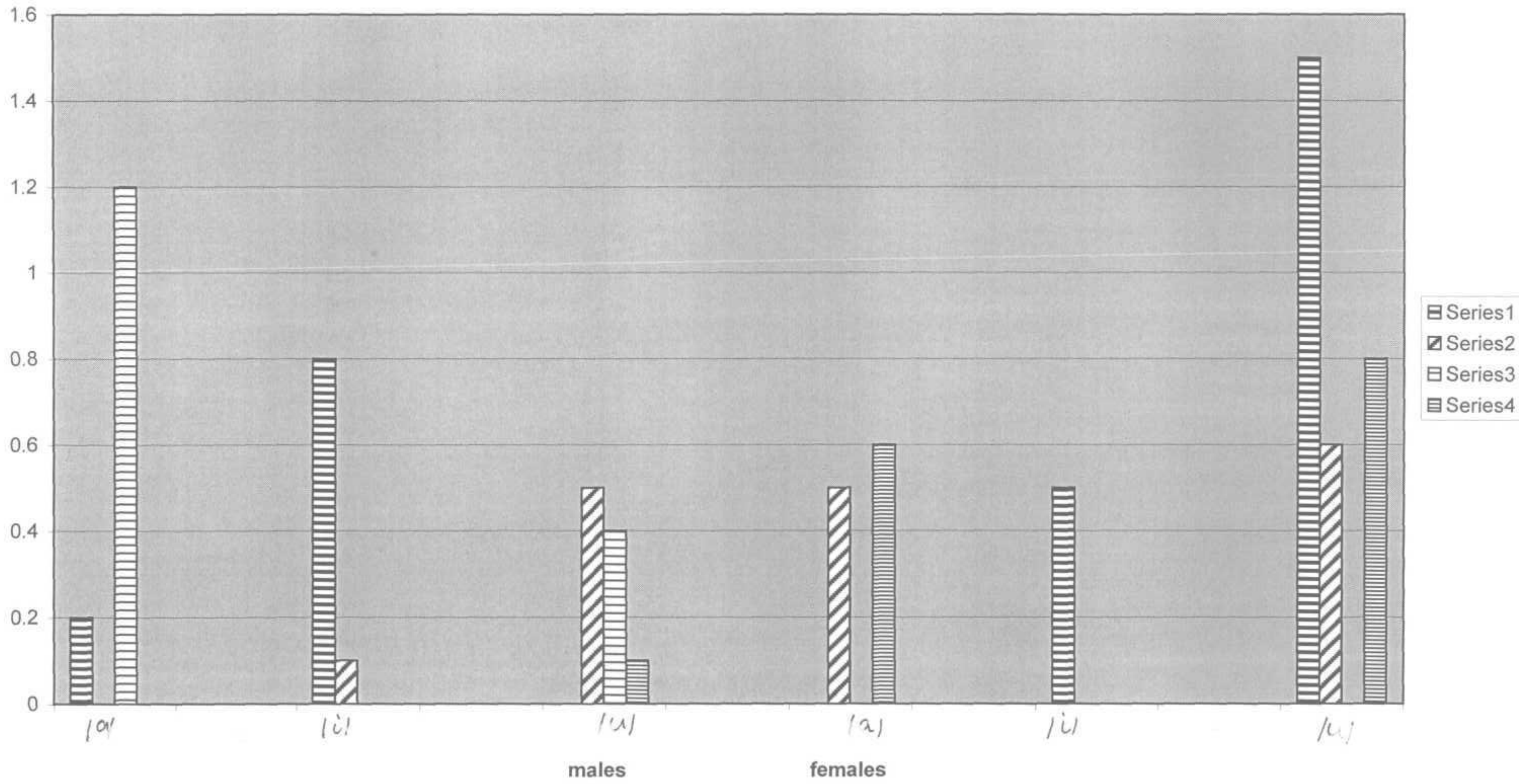
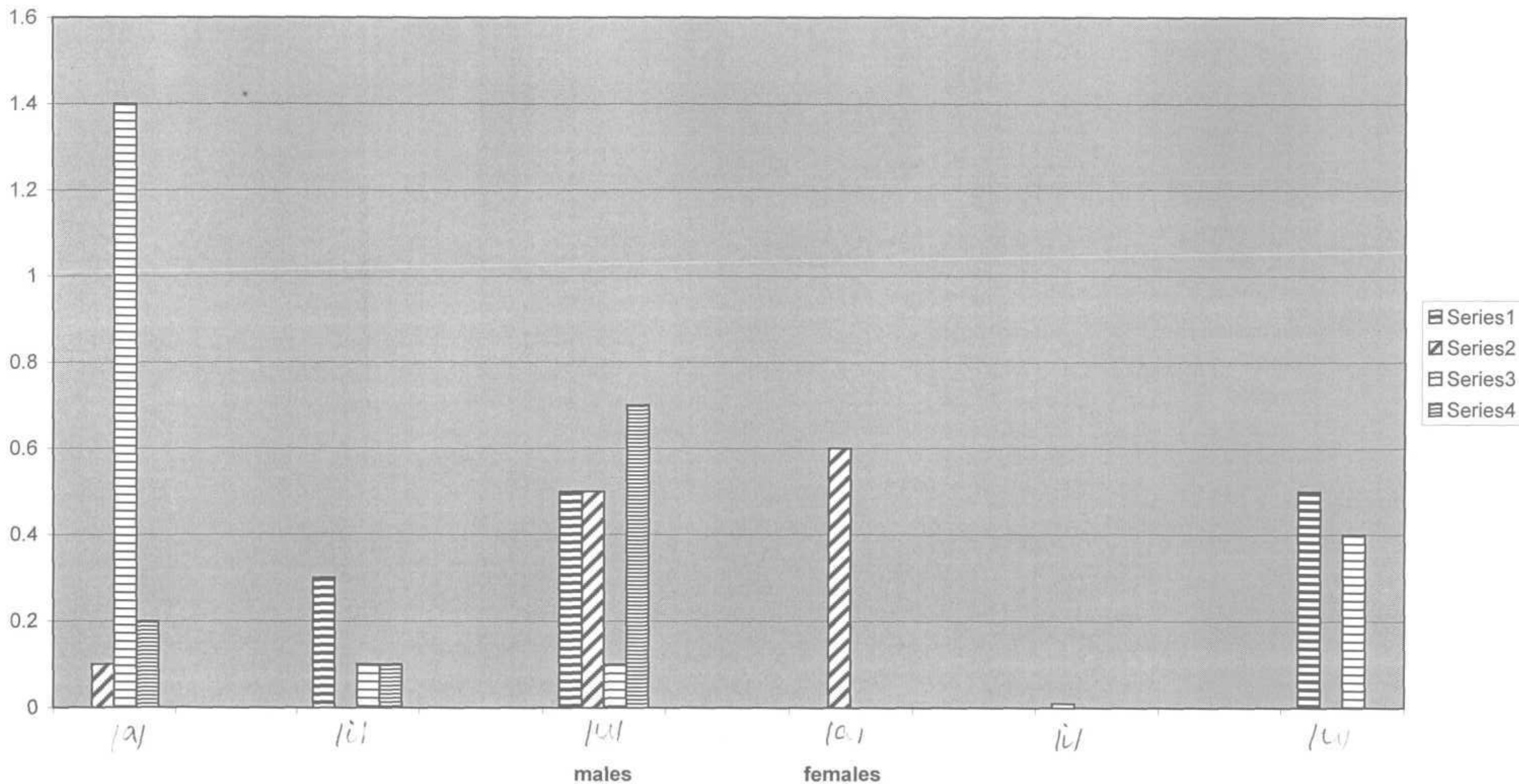


Table -XXIX :- Number of Unvoiced Segments (NITV) values for both males and females in the baseline and the experimental conditions.

CONDITIONS	*MALES*			*FEMALES*		
	/a/	/i/	/u/	/a/	*/i/*	*/u/*
1. Baseline Condition						
Mean	0.00	0.30	0.50	0.00	0.01	0.50
SD	0.00	0.95	1.58	0.00	0.32	1.27
Range	0.00	3.00	5.00	0.00	1.00	4.00
2. Experimental Condition I (Tongue Twister Task)						
Mean	0.10	0.00	0.50	0.60	0.00	0.00
SD	0.32	0.00	1.58	1.90	0.00	0.00
Range	1.00	0.00	5.00	6.00	0.00	0.00
Z- value	0.32 (-)	0.32 (-)	1.00 (-)	0.32 (-)	0.32 (-)	0.18 (-)
3. Experimental Condition II (Tongue Twister with DAF Task)						
Mean	1.40	0.10	0.10	0.00	0.00	0.40
SD	4.43	0.32	0.32	0.00	0.00	1.26
Range	14.00	1.00	1.00	0.00	0.00	4.00
Z- value	0.32 (-)	0.32 (-)	0.32 (-)	1.00 (-)	0.32 (-)	0.78 (-)
4. Experimental condition III (Reverse spelling Task)						
Mean	0.20	0.10	0.70	0.00	0.00	0.00
SD	0.63	0.32	2.21	0.00	0.00	0.00
Range	2.00	1.00	7.00	0.00	0.00	0.00
Z- Value	0.32 (-)	0.65 (-)	0.32 (-)	1.00 (-)	0.32 (-)	0.18 (-)

GRAPH XXIX- Mean values of vowels /a/, /i/ &/u/ for males and females of the Number of unvoiced segments



As a part of the study another experiment was carried out to find out whether the change in voice was due to stress-loaded instruction or the cognitive workload tasks. In this the subjects performed the same experimental tasks but without the stress loaded instructions. The phonation samples were recorded and analysed. Statistical analysis was done to find out the significant difference between the experimental conditions and the baseline measure. The results showed the following :

There was no significant difference between the baseline and the first experimental task i.e., the reading of the tongue twister task, in any of the acoustic parameters measured. This, thus indicating that the cognitive workload task of reading of the tongue twister does not produce any significant change in voice. This can also be attributed to the familiarity of the subjects to the task.

In the other two experimental conditions i.e., reading of the tongue twister with DAF task and reverse spelling task, significant difference was observed in terms of the acoustic parameters measured.

Absolute jitter (Jita) was higher for phonation of |a| and |i| by females and for phonation of |a| by males, in the second experimental task, when compared with the baseline measure. Significant difference was revealed on statistical analysis ($Z = 0.06$ for female |a|; $Z = 0.04$ for female |I|; and $Z = 0.04$ for male |a|). These higher values indicate greater variability in voice and can be due to induced stress. Jita was also higher for phonation of |u| by both males and females in the third experimental task of reverse spelling. Statistical analysis also revealed significant difference between the baseline and this experimental condition ($Z = 0.01$ for females; $Z = 0.04$ for males). These higher values indicate more variability which can be attributed to induced stress by means of cognitive workload task.

Jitter percent (Jitt) was found to be higher in the reverse spelling task when compared with the baseline condition. Statistical analysis showed significant difference with respect to this parameter for phonation |u| by both males and females (Z = 0.01 for females; Z = 0.02 for males). This is also due to increased variability in the vocal cords due to stress.

Significant difference was also revealed between the reverse spelling task and baseline measure in terms of fundamental frequency, for phonation of |i| and |u| by females (Z = 0.01 for |u|; Z = 0.03 for |i|). Fundamental frequency was found to be increased in this experimental condition.

Highest fundamental frequency (Fhi) was also increased in the cognitive workload task of reverse spelling, when compared to the baseline. Statistical analysis revealed significant difference for the phonation of |i| and |u| by males with respect to this parameter (Z = 0.05 for |i|; Z = 0.06 for |u|). Thus the higher Fo and Fhi values can be attributed to increased tenseness in the vocal cords, due to induced stress.

Pitch period perturbation quotient (PPQ) was found to be increased in the second and third experimental task, when compared to the baseline. Statistical analysis revealed significant difference for phonation of |a| by both males and females (Z = 0.06 for females; Z = 0.06 for males) in the second experimental condition; and for phonation of |u| by both males and females (Z = 0.01 for females; Z = 0.02 for males) in the third experimental condition. This is again due to changes in the physiology of the vocal cords due to the presence of stress.

Relative average perturbation (RAP) showed significant difference when the reading of the tongue twister with DAF and reverse spelling conditions were compared with the baseline measure. In the second experimental task, phonation of |a| and i| by males showed significant difference (Z = 0.02 for |a|; Z = 0.06 for |i|). In the third experimental condition, phonation of |u| by both males and females showed significant difference (Z = 0.01 for females; Z = 0.02 for males).

Higher smoothed pitch perturbation quotient (SPPQ) were observed for phonation of |u| by both males and females in the reverse spelling task. Statistical analysis revealed significant difference (Z = 0.02 for females; Z = 0.01 for males) between this experimental and the baseline measure. These higher values can be attributed to the physiological changes owing to the presence of stress due to cognitive workload task.

Amplitude variation (Vam) was also found to be significantly increased in the reverse spelling trask for the phonation of |u| by both males and females (Z = 0.05 for females and Z = 0.04 for males) when compared to the baseline. This indicated greater variability in the vocal cords attributed to the presence of stress.

Thus, the tasks of cognitive workload can induce stress and can thus produce changes in voice. However, this is observed with respect to only few acoustic parameters.

SUMMARY AND CONCLUSION

The demands of time, workload and so on lead to the psychological stress in the individual. The advancement in the society have also led to an increase in the mental effort required by the individual. The need to understand the physiological changes, resulting in voice change due to stress has inspired new interest in understanding the function and dysfunction of human voice. It has been found that the concept of voice change due to stress and its acoustic correlates is poorly understood due to limited research in this area.

The purpose of this study was to find out the acoustic correlates of voice under stressed conditions. A total of 20 normals subjects (10 males and 10 females) were selected for the study. For this purpose, three tasks of cognitive workload were selected. These tasks involved reading of tongue twister, reading of tongue twister under DAF condition and reverse spelling tasks. The phonation of vowels |a|, |i| and |u| during these experimental tasks was compared with the phonation of vowels |a|, |i| and |u| recorded as the baseline measure.

The MDVP model was used to acquire, analyse and display the following twenty-nine voice parameters from a single phonation, for different conditions. All the phonations under different conditions were analysed. These extracted parameters were available as a numerical file which was subjected to statistical analysis.

I. Frequency Parameters :

1. Average fundamental frequency.
2. Average pitch period.
3. Highest fundamental frequency.
4. Lowest fundamental frequency.
5. Standard deviation of fundamental frequency.

6. Fo tremor frequency.
7. Absolute jitter.
8. Jitter percent.
9. Relative average perturbation.
10. Pitch period perturbation quotient.
11. Smoothed pitch period perturbation quotient
12. Fo tremor intensity index.
13. Fundamental frequency of variation.

II. Intensity Parameters :

14. Amplitude tremor frequency.
15. Shimmer in dB
16. Shimmer in percent.
17. Amplitude perturbation quotient.
18. Smoothed amplitude perturbation quotient.
19. Peak amplitude variation.
20. Amplitude tremor intensity index.

III. Other Parameters :

21. Noise to harmonic ratio.
22. Voice turbulence index.
23. Soft phonation index.
24. Degree of voice breaks.
25. Degree of sub-harmonic breaks.
26. Degree of voiceless.
27. Number of voice breaks.
28. Number of sub-harmonic segments.
29. Number of unvoiced segments.

The results were subjected to statistical analysis (Wilcoxn's test of significance and descriptive analysis) using SPSS computer programme. The Wilcoxn test result indicated the following :

1. There was significant difference between the baseline measure and first task of cognitive workload ie.., reading of the tongue twister in the following parameters :

   1. Highest fundamental frequency (Hfo).
   2. Absolute jitter (Jita).
   3. Jitter percent (Jitt).
   4. Relative average perturbation (RAP).
   5. Pitch period perturbation quotient (PPQ).
   6. Voice turbulence index (VTI).

2. There was significant difference between the baseline measure and the second task of cognitive workload i.e., reading of the tongue twister with DAF condition in the following parameters.

   1. Shimmer percent (Shim)
   2. Smoothed amplitude perturbation quotient (SAPQ)
   3. Voice turbulence index (VTI)
   4. Soft phonation index (SPI)

3. There was significant difference between the baseline measure and the third task of cognitive workload i.e., reverse spelling task in the following parameters :

   1. Highest fundamental frequency (Hfo)
   2. Voice turbulence index (VTI)

Thus, the results of this study showed that it was possible to identify psychological stress induced using cognitive workload tasks and instructions in an individual using the above mentioned parameters measured by using multi-dimensional voice profile.

As a part study, an experiment was carried out to find out whether the psychological stress was due to the cognitive workload tasks or the stress loaded instructions. In this experiment, the stress loaded instructions were removed and the tasks of cognitive workload remained the same. Same subjects as above were considered for this experiment. The acoustic parameters were measured using the MDVP software. The statistical analysis revealed the following :

1. There was no significant difference between the baseline measure and the first experimental task of cognitive workload i.e., reading of the tongue twister in any of the parameters.

2. There was significant difference between the baseline measure and the second experimental task of cognitive workload i.e., reading of the tongue twister with DAF condition, in the following parameters.

    1) Absolute Jitter (Jita)
    2) Pitch period perturbation quotient (PPQ)
    3) Relative average perturbation (RAP)

3. There was significant different between the baseline measure and third task of cognitive workload i.e., reverse spelling task in the following parameters;

    1) Absolute jitter (Jita)
    2) Jitter percent (Jitt)
    3) Highest fundamental frequency (Fhi)
    4) Fundamental frequency (Fo)
    5) Pitch period perturbation quotient (PPQ)
    6) Relative average perturbation (RAP)
    7) Smoothed pitch period perturbation quotient (SPPQ)
    8) Coefficient of amplitude variation (Vam)

Thus, these above mentioned parameters were found to be affected in the presence of cognitively induced stress.

From this study, one can infer about the parameters which were affected due to psychological stress in the normal individuals. The sensitive parameters as found in this study could be used to find out the susceptibility of an individual for emotional stress.

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APPENDIX

The definition of the 29 parameters as given in the MDVP manual are as follows :

1. Average Fundamental Frequency (Fo-Hz)

Average value of all extracted period to period fundamental frequency values. Voice break areas are excluded. Fo is computed from the extracted period to period pitch data as :

$$Fo = \frac{1}{N}\sum_{i=1}^{N} Fo^{(i)}$$

Where $Fo^{(i)} = \frac{1}{To^{(i)}}$ = period to period fo frequency.

$To^{(i)}$, i = 1,2 . . . . , N : extracted pitch period data

N = PER - number of extracted pitch periods.

2. Average pitch period (To-msec)

Average volume of all extracted pitch period values voice break areas are excluded.

$$To = \frac{1}{N}\sum_{i=1}^{N} To^{(i)}$$

Where $To^{(i)}$, i = 1,2, ... N : extracted pitch period data.

N = PER - number of extracted pitch periods.

3. Highest fundamental frequency (Fhi-Hz)

The greatest of all extracted period to period fundamental frequency values. Voice break areas are excluded.

It is computed as

Fhi = max [$Fo^{(i)}$] i = 1,2, ... N.

Where $Fo^{(i)} = \frac{1}{To^{(i)}}$ - Period to period fundamental frequency values.

$To^{(i)}$ = i = 1,2, ...N - extracted pitch period data.

4. Lowest fundamental frequency (Flo-Hz)

The lowest of all extracted period to period fundamental frequency values voice break areas are excluded.

$$Flo = \min [Fo^{(i)}],\ i = 1,2,\ .\ .\ .\ .\ N,$$

Where $Fo^{(i)} = \dfrac{1}{To^{(i)}}$ - period fundamental frequency values

$To^{(i)}$ $i = 1,2,\ .\ .\ .\ .N$ - extracted pitch period data.

5. Standard deviation of fundamental frequency (STD-Hz)

Standard deviation of all extracted period to period fundamental frequency values. Voice break areas are excludded.

$$STD = \frac{1}{N} \sum_{i=1}^{N} (Fo - Fo^{(i)})^2$$

Where $Fo = \dfrac{1}{N} \sum_{i=1}^{N} Fo^{(i)} = \dfrac{1}{To^{(i)}}$ - Period to period fundamental frequency values.

$To^{(i)}$ $i = 1,2,\ .\ .\ .\ .\ N$ - extracted pitch period data.

N = number of extracted pitch period data.

6. Fo - Tremor frequency (Fftr-Hz)

The frequency of the most intensive low frequency Fo modulating component in the specified Fo - tremor analysis range. If the corresponding FTRI values is below the threshold, the Fftr value is zero.

7. **Amplitude tremor frequency (Fatr-Hz)**

The frequency of the most intensive low frequency amplitude modulating component in the specified amplitude tremor analysis range. If the corresponding ATRI value is below the specified threshold, the Fatr value is zero.

8. Absolute Jitter (Jita-usec)

An evaluation of the period to period variability of the pitch period within the analyzed voice sample. Voice break areas are excluded.

Jita is computed as :

$$Jita = - \frac{1}{N-1} \sum_{i=1}^{N-1} \left| To^{(i)} - To^{(i+1)} \right|$$

Where $To^{(i)}$ $i = 1,2, \ldots . N$ - extracted pitch period data.

$N = PER$ - number of extracted pitch periods.

Absolute Jitter measures of the pitch short term (cycle-to-cycle) irregularity of the pitch periods in the voice sample. This measure is widely used in the research literature on voice perturbation (Iwata and Vonleden 1970). It is veiy sensitive to the pitch variations occuring between consecutive pitch periods. However, pitch extraction errors may affect absolute jitter significantly. The pitch of the voice can vary for a number of reasons, cycle-to-cycle irregularity can be associated with the inability of the vocal cords to support a periodic vibration for a defined period. Usually this type of variation is random. They are typically associated with hoarse voices.

Both Jita and Jitt represent evaluations of the same type of pitch perturbation. Jita is an absolute measure and shows the result in micro-seconds which makes it dependent on the average fundamental frequency of voice. For this reason, the normative values on Jita for men and women differe significantly. Higher pitch results into lower Jita. That's why, the Jita value of two subjects with different pitch are difficult to compare.

9. Jitter percent (Jitt-%)

Relative evaluation of the period-to-period (every short term) variability of the pitch within the analyzed voice.

$$\text{Jitt} = \frac{\frac{1}{N-1}\sum_{i=1}^{N-1} \left| To^{(i)} - To^{(i-1)} \right|}{\frac{1}{N}\sum_{i=1}^{N} To^{(i)}}$$

'Where $To^{(l)}$, **1=1,2,**. . . . . .N - extracted pitch period data.

N = PER - number of extracted pitch periods.

Jitter percent measures the very short term (cycle-to-cycle) irregularity of the pitch period of the voice. Jitt is a relative measure and the influence of the average fundamental frequency of the subject is significantly reduced.

10. Relative average perturbation (RAP-%)

Relative evaluation of the period-to-period variability of the pitch within the analyzed voice sample with smoothing factor of 3 periods. Voice breaks areas are excluded. It is computed as :

$$\text{RAP} = \frac{\frac{1}{N-2}\sum_{i=2}^{N-1} \left| \frac{To^{(i-1)} + To^{(i)} + To^{(i+1)}}{3} - To^{(i)} \right|}{\frac{1}{N}\sum_{i=1}^{N} To^{(i)}}$$

'Where $To^{(i)}$, i=l,2,. . . . . .N - extracted pitch period data.

N = PER - number of extracted pitch periods.

Relative average perturbation measures the short term (cycle-to-cycle with smoothing factor of 3 periods) irregularity of the pitch period of the voice. The smoothing reduces the sensitivity of RAP to pitch extraction errors. However, it is less sensitive to the very short term period-to-period variations, but describes he short term pitch perturbation of the voice very well. The pitch of the voice can vary for a number of reasons, cycle-to-cycle irregularity can be associated with the inability of the vocal cords to support a periodic vibration with a defined period. Hoarse and/or breathy voices may have an increased RAP.

11. Pitch period perturbation quotient (PPQ-%)

Relative evaluation of the period-to-period variability of the pitch within the analyzed voice sample with a smoothing factor of 5 periods. Voice break areas are excluded. PPQ is computed as,

$$PPQ = \frac{\frac{1}{N-4}\sum_{i=2}^{N-4}\left|\frac{1}{5}\sum_{r=0}^{4} To^{(i+r)} - To^{(i+2)}\right|}{\frac{1}{N}\sum_{i=1}^{N} To^{(i)}}$$

Where $To^{(i)}$, i=1,2,. . . . . .N - extracted pitch period data.

N = PER - number of extracted pitch periods.

PPQ measures the short term (cycle-to-cycle with a smoothing factor of 5 periods) irregularity of the pitch period of the voice. The smoothing reduces the sensitivity of PPQ to pitch-extraction errors while it is less sensitive to period-to-period variations, it describes the short-term pitch perturbation of the voice very well. Hoarse and/or breathy voices may have an increased PPQ.

12. Smoothed pitch period perturbation quotient (SPPQ -%)

Relative evaluation of the short or long term variability of the pitch period within the analyzed voice sample at smoothing factor defined by the user. The factory setup for the smoothing factor defined by the user. The factor setup for the smoothing factor is 55 periods, voice break areas are excluded.

$$SAPQ = \frac{\frac{1}{N-sf+1}\sum_{i=2}^{N-sf+1}\left|\frac{1}{sf}\sum_{r=0}^{sf-1} A^{(i+4)} - A^{(i+m)}\right|}{\frac{1}{N}\sum_{i=1}^{N} A^{(i)}}$$

Where $A^{(l)}$ i = 1,2,. . . . . . .N extracted peak to peak

N = number of extracted impuses amplitude data.

Sf = smoothing factor

SPPQ allows the experimenter to define his own pitch perturbation measure by changing the smoothing factor from 1 to 99 periods. This is desirable because in the scientific literature researchers use pitch perturbation measures with different smoothing factors or without smoothing.

With a small smoothing factor, SPPQ is sensitive mostly to the short-term pitch variation of the voice impulses. With a smoothing factor of 1 (no smoothing), SPPQ is identical to Jitter variations occuring between consecutive pitch periods. Usually this type of variation is random. It is typical for hoarse voices. However, pitch extraction errors may object Jitter percent significantly.

13. Fundamental frequency variation (vFo-%)

Relative standard deviation of the fundamental frequency. It reflects, in general, the variation of Fo (short term to long term), within the analyzed voice sample. Voice break areas are excluded.

$$vFo = \frac{\frac{1}{N}\sum_{i=1}^{N} Fo^{(i)} - Fo^{(i)\ 2}}{\frac{1}{N}\sum_{i=1}^{N} Fo^{(i)}}$$

Where, $Fo = \frac{1}{N}\sum_{i=1}^{N} Fo^{(i)}$

$Fo^{(i)} = \frac{1}{To^{(i)}}$ - period to period Fo values.

N = PER - number of extracted pitch periods.

vFo reveals the variations in the fundamental frequency. The vFo value increases regardless of the type of pitch variation. Either random or regular short term or long term variations increase the value of vFo. Because the sustained phonation normative thresholds assume that the fundamental frequency should not change, any variations in the fundamental frequency are reflected in vFo. These changes could be frequency tremors (i.e., periodic modulation of the voice) or non periodic changes, very high jitter or simply rising or falling pitch over the analysis length.

14. Shimmer in dB (shdB)

Evaluation is dB of the period-to-period (very short term) variability of the peak-to-peak amplitude within the analyzed voice sample voice break areas are excluded.

$$shdB = \frac{1}{n-1} \sum_{i=1}^{N-1} \left| 20 \log(a^{(i+1)} / A^{(i)} \right|$$

Where $A^{(i)}$ i =1,2,. . . . . . .N - extracted peak to peak amplitude data.

N = number of extracted impulses.

Shimmer in dB measures the very short term cycle-to-cycle irregularity of peak-peak amplitude of the voice. This measure is widely used in the research literatrure on voice perturbation (Iwata & VonLeden 1970). It is very sensitive to the amplitude variation occurring between consecutive pitch periods. However, pitch extraction errors may affect shimmer percent significantly.

The amplitude of the voice can vary for a number of reasons. Cycle-to-cycle irregularity of amplitude can be associated with the inability of the vocal folds to support a periodic vibration for a defined period and with the presence of turbulent noise in the voice signal usually this type of variation in random. It is typically associated with hoarse and breathy voices. APQ is the preferred measurement for shimmer because it is less sensitive to pitch extraction errors while still providing a reliable indication of short-term amplitude variability in the voice.

Both Shim and ShdB are relative evaluations of the same type of amplitude perturbation but they use different measures for the result percent anddB.

15. Shimmer percent (Shim-%)

Relative evaluation of the period-to-period (very short term) variation of the peak-to-peak amplitude within the analyzed voice sample voice break means are excluded.

$$Sh = \frac{\frac{1}{N-1}\sum_{i=1}^{N-1}\left|A^{(i)} - A^{(i+1)}\right|}{\frac{1}{N}\sum_{i=1}^{N} A^{(i)}}$$

Where $A^{(i)}$, i=l,2,. . . . . . .N - Extracted peak to peak amplitude
N = number of extracted impulses.

Shimmer percent measure the very short term (cycle-tio-cycle) irregularity of the peak-to-peak amplitude of the voice.

16. Amplitude perturbation quotient (APQ-%)

Relative evaluation of the period-to-period variation, variability of the peak-to-peak amplitude within the analyzed voice sample at smoothing of 11 periods. Voice break areas are excluded.

$$APQ = \frac{\frac{1}{N-4}\sum_{i=2}^{N-4}\left|\frac{1}{5}\sum_{r=0}^{4} A^{(i+r)} - A^{(i+2)}\right|}{\frac{1}{N}\sum_{i=1}^{N} A^{(i)}}$$

Where $A^{(o}$, i = 1,2,. . . . . . .N extracted peak to peak amplitude
N = number of extracted impulses.

APQ measures that the short term (cycle-to-cycle with smoothing factor of 11 periods) irregularity of the peak-to-peak amplitude of the voice while it is less sensitive to the period-to-period amplitude variations it still describes the short term amplitude perturbation of the voice very well breathy and hoarse voice usually have an increased APQ. APQ should be regarded as the preferred measurement for shimmer in MDVP.

17. Smoothed amplitude perturbation quotient (SAPQ-%)

Relative evaluation of the short or long term variability of the peak-to-peak amplitude within the analyzed voice sample at smoothing for the smoothing factor is 55 periods (providing relatively long-term variability the user can change this value as desired) voice break areas are excluded.

$$SAPQ = \frac{\frac{1}{N - sf + 1} \sum_{i=1}^{N=sf+1} \left| \frac{1}{sf} \sum_{r=0}^{sf-1} A^{(i+r)} - A^{(i+m)} \right|}{\frac{1}{N} \sum_{i=1}^{N} A^{(i)}}$$

Where $A^{(i)}$, i=l,2,. . . . . .N - extracted peak-to-peak amplitude data

N = number of extracted impulses,

sf = smoothing factor.

SAPQ allows user to define their own amplitude perturbation measure by changing the smoothing factor from 1 to 99 periods.

18. Peak amplitude variation (Vam-%)

Relative standard deviation of peak-to-peak amplitude. It reflecrts in general the peak-to-peak amplitude variations (short term to long term) within the analyzed voice sample, voice break areas are excluded.

Vam is computed as ratio of the standard deviation to the average value of the extracted peak-to-peak amplitude data as:

$$vAM = \frac{\frac{1}{N} \sum_{i-1}^{N} / \frac{1}{N} \sum_{i=j}^{N} A^{(i)} - A^{(j)2} /}{\frac{1}{N} \sum_{i=1}^{N} A^{(i)}}$$

Where $A^{(i)}$, i =1,2,. . . . .N - extracted peak to peak amplitude data

N = number of extracted impulses.

Vam reveals the variations in the cycle-to-cycle amplitude of the voice. The Vam value increases regardless of the type of amplitude variation. Either random or regular short term or long term variation increase the value of Vam.

19. Noise to harmonic ratio (NHR)

Average ratio of the inharmonic spectral energy in the frequency range (1500 - 4500) Hz to the harmonic spectral energy in the frequency range (70 - 4500) Hz. This is a general evaluation of noise present in the signal analyzed.

20. Soft phonation index (SPI)

Average ratio of the lower frequency harmonic energy (70-1600) Hz to the higher frequency (1600-4500) Hz harmonic energy. Increased value of SPI may be an indication of incompletely or loosely adducted vocal folds during phonation.

21. Vocal turbulence index (VTI)

Vocal turbulence index is an average ratio of the spectral inharmonic high frequency energy in the range (2800 - 5800) Hz to the spectral harmonic energy in the 4500 Hz in areas of the signal where the influence of the frequency and amplitude variations, voice breaks and sub-harmonic components are minimal.

22. Frequency tremor intensity index (FTRI-%)

Average ratio of the frequency magnitude of the most sensitive low-frequency magnitude of the analyzed voice signal.

23. Amplitude tremor intensity index (ATRI-%)

Average ration of the amplitude of the most intense low-frequency amplitude modulating component to the total amplitude of the analyzed voice signal.

The method for computation is same as FTRI except that here the peak to peak amplitude data has been taken into consideration instead of fo data.

24. Degree of voice breaks (DVB-%)

Ratio of the total length of the areas representing voice breaks to the time of the complete voice sample.

$$DVB = \frac{t_1 + t_2 + \ldots t_n}{t_{sam}}$$

Where t1, t2 . . . tn - lengths of the 1st, 2nd,. . . voice

Tsam - Length of analyzed voice data samples.

DVB does not reflect the pauses before the 1^{st} and after the last voiced areas of the recording. It measure the ability of the voice to sustained uninterrupted voicing. The normative threshold is "0" because a normal voice, during the task of sustaining voice, should not have any voice break areas. In cases of phonation with pauses (such as running speech, voice breaks, delayed start or earlier and of sustained phonation) DVB evaluates only the pauses between the voiced areas.

25.Degree of subharmonic segments (DSH-%)

Relative evaluation of sub-harmonic to Fo components in the voice sample.

26. Degree of unvoiced segments (DUV-%)

Estimated relative evaluation of nonharmonic areas (where Fo cannot be detected) in the voice samples.

27. Number of voice breaks (NVB)

Number of times the fundamental period was interrupted during the voice sample (measured from the first detected period to the last period).

28. Number of subharmonic segments (NSH)

Number of autocorrelation segments where the pitch was found to be a sub-harmonic of Fo.

29. Number of unvoiced segments (NUV)

Number of unvoiced segments detected during the autocorrelation analysis.