"VOICE PARAMETERS IN DEVELOPMENTAL SPEECH AND LANGUAGE DISORDERS"

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

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Dedicated to
"The Lord Jesus Christ"
Lord of my life who is the rock of my Salvation.

"Susha and Varun"
(My favourites who have challenged me in therapy)

CERTIFICATE

This is to Certify that this Dissertation entitled "Voice Parameters in Developmental Speech and Language Disorders" is the bonafide work in part fulfillment for the degree of Master of Science (Speech and Hearing) of the student with Register No. M9803.

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CERTIFICATE

This is to certify that the dissertation entitled "Voice Parameters in Developmental Speech and Language Disorders" has been prepared under my supervision and guidance.

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DECLARATION

This Dissertation entitled "Voice Parameters in Developmental Speech and Language Disorders" 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.*

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INTRODUCTION

Human speech is an integral part of human Linguistic ability by which transmission of information is carried out according to the uniqueness of the mind. Speech may be defined as a form of oral communication in which the transformation of information takes place by means of aC oustic energy. The speech waveforms are the result of interaction of one or more source with the vocal tract filter system (Fant 1960).

The biological substrate of human speech involves an interplay between biological mechanisms that have other vegetative functions and neural and anatomical mechanisms that appear to have evolved primarily for their role in facilitating human vocal communication.

The production of voice is a complex process which depends on sensory motor integration i.e., synchrony between the respiratory, the phonatory, the resonatory and the articulatory system 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 centers 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".

Voice production can be thought of as the activation of an entire system of coupled oscillators. The intent to vocalise activates motor commands that are responsible for the neural inputs to an array of biochemical, neural, and acoustic oscillators. The vocal folds are the primary oscillating system that produce the carrier signal (the glottal air-flow). All other oscillators can then be thought of as modulators of the carrier signal. Some of the modulations are nearly sinusoidal (respiratory, heart beat) but many are high dimensional (action potentials of muscles, air vortices, mucous in morion). Yet others are passive oscillators (tracheal resonator, supraglottal vocal tract, various sinuses) that can influence the primary oscillating system.

It can be assumed that the system of coupled oscillators contains and releases information about the human body; in particular, about its genetics, development, age, disease, language, culture, food and drug intake and response to the environment. There are several means of analysing voice, developed by different workers, to note the factors which are responsible for creating an impression of a particular voice" (Hirano, 1981; Nataraja, 1972; Rashmi, 1985; Anitha 1994).

The psycho-acoustic evaluation of voice is done based on pitch, loudness and quality of the voice sample. Due to its subjectivity the perceptual judgement of voice has been considered less worthy than the objective measurements. Presently acoustic analysis of voice is gaining more importance. There are other objective measuresjmethods Like EMG, stroboscopy, ultra sound glottography, ultra high photography, photo-electric photography, electroglottography, aerodynamic measurements, acoustic analysis, etc.

Acoustic analysis can be done using methods such as spectrography, peak analysis, inverse filtering computer based methods and others.

These has been increasing evidence for the application of acoustic analysis to the study of speech development in children. Research background can be organised with respect to data which has been collected in three major areas:

(i) Vocal fundamental frequency (Fo)

(ii)Static formant patterns of vocalic sounds.

(iii)Timing and coordination of articulation.

Sometimes the physiologic and phonetic interpretation of acoustic data are uncertain, but acoustic analysis is appropriate to test certain hypothesis about developmental changes in anatomy, motor control and phonological function.

Developmental changes in mean Fo :

The ages of most rapid change in Fo are the first four months, the period of one-three years and the period of 13 - 17 years. Little change in the mean Fo occurs during the period of three five years, which Negus (1962) identifies as an interval of rapid laryngeal growth. Kaplan (1960), also noted that laryngeal growth occurs primarily during the first three years and during puberty. Possibly, the age-related differences in mean Fo are caused as much by variations in the vocalization activities as by anatomical and physiological maturation.

Variability of Fundamental frequency :

Relatively little information is available on developmental change in the range variability of Fo. Most of the literature on the new born infants cry indicates that Fo falls in the range of 400 - 600 Hz, although the ability of extending this range in either direction is appreciable.

Studies have shown that even in very young children, the physiological range of voice has a broad, almost adult range two-and-one-half to three octaves. If a conclusion is forced from these rather limited data it would be that the range of vocal frequency does not change appreciably during maturation.

A general conclusion that may be drawn from acoustic studies of speech development is that, beginning by at least three years of age, the variability of speech motor control progressively diminishes until the age of 8 to 12 years i.e., progressively neuromuscular control is achieved with age. Adult-like stability is achieved around 12-14 years.

The exact age at which minimum variability is attained probably depends upon several factors, but of certain importance are :

The child's individual pattern of motor development and the particular type of speech behaviour that is under examination (Kent, 1976).

Feasibility of acoustic investigation of children's speech is often hampered by pecularities of a child's speech production Like inappropriate nazalisation, occurrence of hoarseness or breathiness, which contribute noise components that may obscure other acoustic details or by limitations of analysis techniques that have been perfected largely on adult speech.

Although the existing data on the acoustic properties of children's speech are all too sketchy in nature, they hold the promise of sensitive methods for the study of speech maturation and developmental disorders.

There has been evidence from infant cry analysis that, some of the acoustic features such as increase in the fundamental frequency, thought to only characterize brain damage, now are known to also be found in pre-term infants, growth retarded infants or infants in whom the e may be no sign as yet identified but who later succumb to sudden infant death syndrome. (Lester, 1984; Lester and Zeskind 1982). According to Vuorenkoski et.al (1971) an abnormally high Fo may be expected for infants with asphyxia, brain damage and hyper bilirubinemia, whereas a low Fo may be expected for infants with Down's syndrome. An implication from these studies is that no single measure such as average fundamental frequency is likely to discriminate normal from abnormal infants.

Variability in the fundamental frequency, combinations of acoustic features will be necessary to identify pathology.

Some acoustic features may be more of a general statement about the functional status or organisation of the nervous sytem than a specific indicator disease, lesion or structural defect in the nervous system.

Tenold et.al (1974) demonstrates that analysis techniques based on the source-filter theory of vowel production (Fant, 1970) can provide information on both the control of laryngeal vibration and the control of the resonating vocal tract.

As mentioned earlier speech is a highly integrated physiological motor act. For each sound there is a separate neuromuscular configuration that involves as a functional unit, all musculature of the speech organ. Any disturbance of this neuromuscular configuration as a result of the weakness , paralysis or incoordination of the speech musculature or as a result of lesions in the nerves supplying the musculature, results in speech dysfunctions.

Cerebral palsy is such a condition where in motor dysfunction secondary to CNS damage before, during or shortly after birth occurs (Boone, 1971). Cerebral palsied children have sensory, motor, perceptual behavioural and emotional problems. Speech abnormalities are often seen in them as all the subsystems of speech production, respiration, phonation, resonation, articulation and prosody are affected.

Predictably these changes in the subsystems of speech production leads to change in the acoustic characteristics of speech. Respiratory abnormalities, inability to extend the exhalation, abnormal vocal fold vibration, abnormal resonance, malpositioning of articulators may all contribute to poor voice characteristics in cerebral palsied children. Since acoustic characteristics reflects the changes in the vocal system and its function, they have been used to study the nature and function of the speech mechanism. In the event of abnormal structural and functional changes, there will be a corresponding change in the acoustic characteristic of speech. Acoustic parameters have been found to be affected in cerebral palsied children (Duffey, 1958; Mc Donald and Chance, 1964; Palmer 1953; Rutherford, 1944;Warnas, 1993).

Recent trends have been the hypothesis there is brain pathology involved in the syndrome of autism. Pronovost et al, 1966 have reported marked deficiencies in the control of respiratory and oral musculature. Higher pitch levels with insufficient pitch levels have been reported in literature. (Goldfarb et al., 1956;

Goldfarb et al., 1972). Other vocal idiosyncrasies that have been noted include hoarseness, harshness, and hypernasality (Pronovost et al., 1966).

Acoustic parameters of the hearing impaired has been found to be different from normals. Increased pitch and poor control have been reported. (Calvert, 1962, Hood, 1966; Martony 1968. Increased laryngeal tension of the vocal folds have been proposed by Martony, 1968).

Thus abnormalities in acoustic parameters have been found to be present in the above mentioned disorders of cerebral palsy, autism, mental retardation and hearing impairment. Acoustic analysis of children's speech has tried to correlate changes in acoustic parameters as an index of the maturation of the speech mechanism.

The present study aims to find out:

1. If certain acoustic parameters would be able to index maturational delay of the speech mechanism in developmental disorders like cerebral palsy, mental retardation, autism and hearing-impairment where speech language retardation is seen.
2. If these parameters of voice could be used to differentially diagnose between developmental disorders.

Null Hypothesis

There is no significant difference in terms of acoustic parameters measured using MDVP, between the normal subjects and subjects of the developmental speech and language disordered groups of cerebral palsy, mental retardation, autism, hearing impairment.

Limitations of the study :

1. Subjects in the developmentally disordered groups of cerebral palsy, mental retardation, autism and hearing impairment have not been age and sex matched across groups.
2. Between group comparison was not possible due to above limitation.

3. Number of subjects within a particular age range was limited to one.
4. Comparison across age ranges was not possible due to limitation No.3.
5. Variable of microphone being held at 4 - 6 inches from subjects could not be maintained in cases of hyperactivity in the subjects that formed the experimental groups.

Implications of the study

1. Objective analysis of voice in the developmentally disordered population may be able to correlate changes in acoustic parameters of voice as an index of the delay in the maruration of the speech mechanism implying an abnormality in neuromotor speech control.
2. Efficacy of voice parameters to differentiate between voice of developmentally disordered populations and normals.
3. Differential diagnosis between developmental disorders using parameters of voice.
4. More effective and early therapeutic intervention in developmentally disordered populations.
5. To consider aspects of voice within a wholistic frame work of treatment especially in disorders like autism.
6. Probability of voice parameters aiding in identifying subgroups within a developmentally disordered population.

REVIEW OF LITERATURE

Communication has been recognised as one of the most fundamental components of human behaviour. The ability of the human beings to use their vocal apparatus with other organs to express their feelings, to describe an event and to establish communication is unique to them. All human societies and only human societies communicate via a system of arbitrary vocal signs. Speech is a form of language that consists of the sounds produced by utilising the flow of air from the lungs. Speech may be defined as a form of oral communication in which the transformation of information takes place by means of acoustic energy. The speech waveforms are the result of interaction of one or more sources with the vocal tract filter system (Fant, 1960).

Speech is produced without observable efforts by human beings. The range of speech variation is immense and yet considered normal. Speech gives information about the specific character of vocal tract of the speaker, which enables one to recognise the speaker's voice, physical well-being and emotional state, attitude towards the entire content in which the speech event occurs.

Speech is considered as skilled, willful and elaborate movements of muscles used for initiating vocal sounds, plus the molding of these sounds into meaningful, oral communication. The production of speech is exercised by the simalteneous, highly co-ordinated and specifically differentiated functions of various systems, respiration phonation and articulation.

According to Boone (1971), "the act of speaking is a very specialised way of using the vocal mechanism. The act of singing is even more so. Speaking and singing demand a combination or interaction of the mechanisms of respiration, phonation, resonation and speech articulation".

The underlying basis of speech is voice. The production of voice depends upon three primary factors: Pulonomic pressure (supplied by respiratory system) laryngeal vibration (phonation) and transfer function of the vocal tract (resonance). The production of voice depends on the synchrony or co-ordination between the above systems.. The respiratory system is the main supplier of energy for the sound production and thus its disorders are mainly reflected as an alternation in the efficiency of the activator to provide satisfactory air support for normal laryngeal function. Respiration provides the initial power and energy source for vocalisation.

The crucial event essential for voice production is vibration of the vocal folds converting aerodynamic energy to acoustic energy. From this point of view parameters involved in the process of phonation can be divided into three major groups:

1. The parameters which regulate the vibrator}" pattern of the vocal folds.
2. The parameters which specify the vibratory pattern of the vocal folds.
3. The parameters which specify the nature of sound generated (Cotz, 1961).

Hirano (1981) has further elaborated on this, by stating that "The parameters which regulate the vibratory pattern of the vocal folds can be divided into two groups - physiological and physical. The physiological factors are those related to the activity of the respiratory, phonatory and articulatory muscles. The physiological factors of genetic endowment of physical structures, the health of the individual and any specific condition may affect the voice. The health of an individual may be indicated by qualities of voice that portray pain, respiratory disease or by those that show fitness and well being. The physical factors include the expiratory force, the conditions of the vocal folds and the state of the vocal tract.

The expiratory force is the energy source of phonation and is regulated chiefly by the respiratory muscles and the state of the broncho-pulmonary system and thoraxic cage. The condition of the vocal folds which are the vibrators is described with respect to the position, shape, size, elasticity and viscosity of the vocal folds. It is influenced by the activity of the laryngeal muscles, and pathological conditions of the vocal folds and the adjacent structures. The state of the vocal tract, the channel between the glottis and the lips, affects the vibratory pattern of the vocal folds to a certain extent and it is regulated chiefly by the articulatory muscles. These primary physical factors in turn determine certain secondary features, which include the pressure drop across the glottis, volume - velocity or mean air flow rate, and glottal impedance or mean glottal resistence. These secondary features are referred to as the aerodynamic parameters.

The vibratory pattern of the vocal folds can be described with respect to the various parameters including the fundamental frequency, regularity or periodicity in successive vibrations, symmetry between the two vocal folds, uniformity in the movement at different points within each vocal fold, glottal closure during vibration, contact between the two vocal folds and so on.

"The vocal fold vibration provides a wide spectrum of quasi-periodic modulations of the air stream accounting for various tonal qualities, reflecting different ways the \ibrator behaves" Bracket (1971). This tone produced by the larynx consists of frequencies ranging from 80 Hz. to 8 kHz and includes fundamental and harmonic frequencies (Fletcher 1954).

"Resonators at least supraglottal, amplify and modify the voice, ie., they make the vocal tones audible and give them a human quality. It has been widely accepted that the resonators are one of the main determinants of voice quality". (Berry & Eisenson, 1962). According to Michel & Wendahl (1971), "the coupled oropharyngeal resonator is responsible for both speech statics and dynamics".

The nature of sound generated is chiefly determined by the vibratory pattern of the vocal folds. It can be specified both in acoustic terms and in psycho-acoustic terms. The psycho-acoustic parameters are naturally dependent on the acoustic parameters. The acoustic parameters are fundamental frequency, intensity, acoustic spectrum and their time-related variations. The psycho-acoustic parameters are pitch, loudness and quality of the voice and their time related variations.

Hirano (1981) has pointed out that the acoustic analysis of the voice signal may be one of the most attractive methods for assessing phonatory functions or laryngeal pathology because it is non-invasive and provides objective and qualitative data. Deliyski (1990) presented an acoustic model of pathological voice production which describes the non-linear effects occuring in the acoustic wave form of disordered voices i.e.. the noise components such as fundamental frequency and amplitude irregularities and variations. Sub-harmonic components, turbulent noise and voice breaks are formally expressed as a result of random time function influence on the excitation function and the glottal filter. Quantitative evaluation of these random functions is done by computation of their statistical characteristics which are useful in assessing voice in clinical practice. This set of parameters which correspond to the model, allow a multidimensional voice quality assessment. Since any single acoustic parameter is not sufficient to demonstrate the entire spectrum of vocal function or of laiyngeal pathology, multi-dimensional analysis using multiple acoustic parameter has been attempted by some investigators. Davis (1976) used paramters such as pitch perturbation quotient, amplitude perturbation quotient, pitch amplitude, coefficient of excess, spectral flatness of the inverse filter spectrum and spectral flatness of the residue signal spectrum and performed multidimensional analysis aiming at differentiation of pathological voices from normal voices.

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

1. Air flow :
   Phonation quotient (PQ)
   Vocal velocity index (WI)
   Maximum Phonation time (MPT)
2. Fo range :
   SPL range
   Habitual Fo
   Habitual SPL
3. Electroglottography :
4. Tape recording
5. Pitch perturbation
6. Amplitude perturbation
7. S/N ratio
8. LTAS
9. Inverse fitler acoustic
10. VOT
11. Perceptual evaluation
12. Laryngeal mirror
13. Fibroscopy of larynx
14. Microscopy of larynx
15. X-ray laryngogrphy
16. Audiometry.

There are various objective methods to evaluate these parameters. Stroboscopic procedure, Purdue pitch meter, high speed cinematography, electroglottography, digi pitch, pitch computer, ultrasonic recordings and the high resolution signal analyser. But at present various computer based methods are being evolved which are very fast in terms of analysing the voice samples and giving the values of the parameters as such. Recently these methods are being used mostly in clinical and research work because they are time saving and they don't need interpretation on the part of experimenter since the parameters are automatically analysed.

Acoustic analysis of voice has been considered to be useful in knowing more about the developmental disorders and thus in the treatment of developmental disorders of speech. In many important respects, the development of motor control for speech is one instance of the more general problem of the development of skilled action. In defining this general problem, Bruner (1973) viewed it as the construction of serially ordered acts, the performance of which is modified to achieve diminishing variability, increased anticipation and improved economy. These attributes seen highly appropriate to describe the development of motor control for speech (Kent, 1980). It seems inescapable that an understanding of a child's mutual acquisition of speech and language requires systematic and thorough investigation of developmental process in speech motor control.

Over the past twenty years, considerable research effort has been directed towards obtaining an understanding of the organisation and control of the processes by which children learn to produce speech. Such research has involved observations of the aerodynamic and acoustic characteristics of speech (Moll,Zimmerman and Smith, 1976). Speech is a motor activity which is controlled by the nervous system, which comprises of central and peripheral divisions.. The three kinds of nerve fibre carried by various trunks in the CNS play different roles in the sensory-motor processes of speech are as follows :

a) The afferent fibres most important in speech are those carried by eighth cranial nerve, the auditory nerve through the agency of which one hears others and oneself and thus leams to perceive and produce speech.

b) Motor fibres innervating the muscles of respiration, phonation and articulation are distributed through many cranial and spinal trunks.

c) The fibres that inter-connect the autonomic nervous system with the CNS thus providing for the interplay of emotional reactions in the two systems (are also carried by many cranial and spinal trunks).

The efferent nerves connect the CNS with the skeletal muscles which include the muscles of the abdomen, diaphragm, larynx, pharynx, velum, tongue, jaw and lips. These nerves carry not only the voluntary impulses to these muscles, but also the impulses from the centres of the CNS (over which one has little, if any direct voluntary control), eg., gagging and sneezing, and also the impulses from CNS centres over which one has partial voluntary control, eg. swallowing, crying, sleeping, smiling and breathing. Some of the centres of CNS important in speech are:

1. The hypothalamus and thalamus
2. The basal ganglia
3. The cerebellum
4. The medulla oblangata
5. The reticular system
6. The cerebral cortex

1. The hypothalamus are located in the centre for the control of visceral organs and involved in emotional reactions.

2. The thalamus : Many have attributed speech and language as the function of the dominant thalamus. Coppa et.al (1979) maintained that the left thalamus contributed to the semantic level of the verbal behaviour which was initially controlled by the marginal areas of the language. Ojemann et.al (1971) proposed that the left thalamus was involved with attention mechanisms which were important to control storage and retrieval of both long term and short term memory. Ojemann **(1971**) also noted that left thalamic mechanisms secured to be involved in the co-ordination of motor and respiratory aspects of speech.

Penfield and Roberts (1959) suggested that the thalamus was a major integrating centre between the frontal and parietal cortical language areas by means of projection fibres. Thus from the reviewed data it seems that dominant thalamus does participate in speech and language functions. Above the thalamus are the basal-ganglia, consisting the striate bodies. These are the emotional centres that colour and sometimes block speech. These ganglia or nuclei are located deep within the cerebrum on either side of the midline.

3. The cerebellum : Cerebellum is a clearing house for all impulses sent to the striped muscles of the body. Without this centre, a given set of muscles could engage in only one activity at a time, because these acts require the co-ordination of largely overlapping sets of muscles and in some instances require opposing movements. This organ also maintains the body in a state of balance with respect to the pull of gravity. For this the cerebellum holds the striped muscles of the body in a constant state of stretch (muscular tone).

The cerebellar function in motor control are thought to be in:

1. The biasing of the muscle spindles to ensure that spindle formation of the appropriate nature is supplied to the higher centres as a movement is performed.
2. The integration and interpretation of afferent information.
3. To exercise a revisory control over the command issued by motor cortex.

Boylls (1975) argued that damage to cerebellum leads to disturbance of entire acts or sequence of movement or there will be evidence of a breakdown in the temporal relationships of movements. Thus cerebellum plays an important role in the temporal relationships of movements. Thus the cerebellum plays an important role in speech, a finely coordinated motor act.

4. The medulla oblongata :The bulbous portion of the spinal cord extending in the cranium is medulla oblongata. Various centres are located here, among them the pneumo-toxic centre which controls the rate and depth of respiratory movements is also present and is important for speech.

5. The reticular formation : All sensory input enter brain proper via thalamus. Parallel with the sensory nerves via the thalamus is a series of reticulate structures through which the incoming stimuli pass and in which they are sorted out. Those impulses that are meaningful to the individual are relayed to the cerebral centres in which they can produce appropriate reaction. Those impulses that are relatively meaningless are shunted out of cerebral circuits. In co-operation with the sensory areas of cerebrum, the reticular formation serves as an arousal mechanism to alert the individual to meaningful patterns of stimulation. The process of attention and alarm are negotiated by the co-operation between the reticular formation and the auditory centre of the left cortex.

6. The cerebral cortex : The sensory centres involved in speech assist the motor areas of the cortex in the processes of motor co-ordination, to learn, guide and check the movements of speech organs. For this, certain connective pathways are necessary between the sensory and the motor areas.

West and Ansberry (1968) quote:. . . . ."normally the areas of the cerebral cortex that are developed to perform this function of association lie either in one hemisphere or the other. These areas developed only on one side of the cortex are the association areas, hi a right handed person association area, most important in motor speech lies close to and in front of the lower end of the primary motor area i.e., 'Brocas' area. As the corpus callosum connects *the* two hemispheres of the cerebrum, it is possible to control the motor system from centres located only on one side. The control exerted by these association centres is by relaying selected impulses from the sensory areas. The association areas of the cortex are more inhibiting than executory in their motor effects. Normally they never excite a muscle group without inhibiting its antagonistic group. They frequently delay the passage of an impulse to the motor outlets of the brain and this provides for the element of timing the most motor co-ordinations required.

Speech is thus built up by conditioning the association areas by impulses from the visual area, the auditory area and the somesthetic area. For each speech sound there is a separate neuro-muscular configuration that involves a functional unit for all the musculature of speech organ. The crucial event essential for the voice production is vibration of the vocal folds.

The vocal fold movement is controlled by a subtle, delicate interplay of various muscles which work in pairs and groups. The adduction vocal folds is brought about by lateral crico-arytenoid and arytenoid muscles. Contraction of arytenoid muscles draw the muscular process posteriorly, thus toeing out the vocal process. When just the lateral crico-arytenoid muscles are contracted, the arytenoid cartilages are rotated so that the muscular process are pulled anteriorly and the vocal processes are toed inward to produce the glottal configuration required for the production of a whisper. Simultaneous contraction of lateral circo-arytenoid and arytenoid muscles approximate the arytenoid cartilages and the vocal folds or that their medial borders are paralleled. The result of combined action of muscles is such that vocal folds are tightly approximated and *if* exhalation is initiated, the vocal folds will be set into vibration to produce a laryngeal tone.

An increase in tension and a concommitant decrease in mass of the vocal folds is primarily responsible for an increase in pitch. This is brought about by the antagonistic action of crico-thyroid and thyro-arytenoid muscle with an assistance from posterior crico-arytenoid muscles. Lowering of the pitch is brought about by the action of thyro-arytenoid muscle which draws the arytenoid and the thyroid cartilage towards one another to shorten and relax the vocal ligament. Medial compression at low pitches is probably facilitated by the lateral crico-arytenoid muscles. The accessory fibres carried by the vagus nerve supplies the intrinsic muscles of larynx controlling the vocal fold vibration.

Speech output depends on the adequate functioning of respiratory, phonatory, resonatory and articulatoiy mechanism. Each of these sub-systems contributes equally to the ultimate speech output in terms of adult standards. It has been seen that young infants produce speech which are quite unlike those of adult speech output in terms of temporal patterning, overall resonance and spectral characteristics though they may seem similar perceptually Stark et.al 1975; Oiler, 1978). This may be because of immature sub-system in terms of structure, function, neuro-muscular connections, etc. The respiratory, phonatory, resonatory and articulatory systrems contribute to speech output.

Respiratory System

The primary or biological function of the respiratory apparatus has been modified in humans to allow for oral communication. The lungs store energy that powers the expiratory phase of respiration during inspiration. The intercostal and abdominal muscles squeeze inward on the pleural space and contributes power for the expiration of air. The main force that powers the expiratory phase of respiration, is the elastic recoil force of the lungs. A number of layered feed back mechanism including the mechanical stretch receptors in lung tissue, central and peripheral chemorecptors monitor breathing in human beings. These chemoreceptive feedback mechanism acts rapidly to make small changes in respiration. (Lieberman & Lierbman 1973) Breathing is managed by a complicated respiratory reflex involving the two vagus nerves and two phrenic nerves from the cervical section of the spinal cord.

Breathing for speech is essentially the same process as breathing for Life, consisting of two phases: inhalation and exhalation. Speech is produced by the displacement of a column of air during exhalation. During speech inspiration becomes shorter than expiration. Air is taken into the lungs and then held for a slow release to allow for an extended period of speech while maintaining a constant subglottal pressure that range from about 8 -10 cm of H_2O (Bouhuys 1974; Draper, Lade Foged & Whitteridge 1960; Lieberman 1967; Liebennan 1968). This steady air pressure is maintained through out the length of expiration. The length of expiration and depth of inspiration that proceeds an expiration are key to the length of the unit of speech that they are going to produce (Lieberman & Lieberman 1973).

Resonatory system

Resonance is the modification of the vocal tone as the airstream passes through the nose and oropharynx and mouth. The modification or amplification creates the individual characteristics of the voice. Resonators of human body used for speech are three tubes; the cavities of which contain column of air, these tubes are pharynx (nasopharynx, laryngo-pharynx), the mouth and the nose (a double tube). Besides these tubes there are larynx the trachea and the bronchi and also sinuses (frontal, maxillary, ethmoid and sphenoid sinuses). The most significant of these cavities are mouth and pharynx. Their importance lies in their extreme adjustability as to their own length and diameter and as to the diameter and length, of their orifices or openings.

Due to the shape of vocal tract (above and below the larynx), various harmonics are resonated to create a much more complex sound. The majority of the resonance effect appears in the ability to articulate. Nasal resonance acts as a continuous and universal modifier of the voice (Greene 1956). The remarkable characteristics of human vocal resonator is that its shape can be altered by the movements of articulators. The speech sounds which are known as vowels, diphthongs, semi-vowels and nasals are the result of filtering the periodic wave produced at the glottis through the vocal tract which varies its configuration and thereby its resonant frequencies for each sound. The ca\ity variations and resonance changes make the sounds distinctive.

Articulatory system

Articulation refers to the ability to modify or valve the voice stream into specific sounds that can be formed into words, sentences of a language.

Articulation occurs by the movement of structures associated with oral cavity. By varying the size and shape of the cavity different sounds are created. Tongue is the most important structure in articulation. It alters the size and shape of the oral and pharyngeal cavities producing most consonants by movements near to or against teeth, gums and palate. Movement of articulators are necessary both for producing resonance characteristics of vocal tract.

Articulatory muscles are innervated by cranial nerves i.e., trigeminal nerve (5th) inn ervating the buccinator and the tensor palatini and the facial nerve innervates the remaining musculature of face. The tongue is innervated by hypo-glossal nerve (12th) while soft palate by glosso-pharyngeal and vagus nerve. So articulation is a fine motor act that requires precise control and timing of articulators.

Phonatory system

Phonation is the sound production by the larynx. The crucial event for voice production is the vibration of vocal folds which is controlled by a subtle and delicate interplay of various muscles. Efficient phonatory behaviour depends on co-ordination between inspiratory and expiratory muscles which then, must be co-ordinated with laryngeal, velopharyngeal and articulatory muscles valving activity. The vocal product of this complex co-ordination is monitored primarily by the auditory system. The nature of sound generated is chiefly by the vibratory pattern of the vocal folds. It can be specified both in acoustic terms and in psychoacoustic terms. The psycho-acoustic parameters are naturally dependent upon the acoustic parameters. The acoustic parameters are fundamental frequency, intensity, spectrum and their time related variations. The psychoacoustic parameters are pitch, loudness, and quality of the voice and their time related variations.

Analysis of acoustic parameters have been considered to be useful in knowing about the developmental disorder and thus in the treatment of developmental disorders of speech.

In many important respects, the development of motor control for speech is oneinstance of the more general problem of the development of skilled action, hi defining this general problem of serially ordered acts, the performance of which is modified to achieve diminishing variability increased anticipation and improved economy. These attributes are seen highly appropriate to describe the development of motor control for speech (Kent, 1980).

Over the past two or three decades considerable research effort has been directed towards obtaining an understanding of the organization and control of the process by which children learn to produce speech. Such research has involved observations of the aerodynamic and acoustic characteristic of speech (Moll, Zimmerman and Smith, 1976).

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. The technique of acoustic analysis has promising future as a diagnostic tool in the management of voice disorders. Many acoustic parameters, derived by various methods, have been reported to be useful in differentiating between the pathological voice and the normal voice. Hirano (1981) goes onto say that all the previous reports are preliminary reports and that further extensive basic and clinical research is required in order to obtain some algorithm for diagnostic purposes.

Further, a clinician will not really know what to expect with a medical diagnosis having a complete physical description of the laryngeal together with some adjectives like "hoarse" for "rough", until he actually sees the case (Michel and Wendhal, 1971). On the other hand, if the clinician receives report which include measures of frequency ranges, respiratory function, jttter, volume-velocity of airflow during sustained phonation etc., in the form of a voice profile, the clinician can compare these values to the norms for each one of the parameters and thus have a relatively good idea as to how to proceed with therapy even before seeing the patient. Moreover, periodic measurement of these parameters during course of therapy may well provide a useful index as to the success of the treatment.

Human neuromotor system involves a complex act. For any motor act to take place a co-ordination in terms of muscle strength, speed of movement, appropriate range of excursion, accuracy of movement, motor steadiness and muscle tone is required. Damage that impairs one or more of these neuromuscular functions may affect motor production (Netsell, 1984).

Speech is a highly integrated physiological motor act and basically results by three motor processes; exhalation, phonation and articulation. For exhalation muscles of thorax and abdomen are responsible; for phonation, muscles of larynx; and for articulation, muscles of articulators like lips, tongue, cheekjaw, pharynx and velum are responsible. For each speech sound there is a separate neuromuscular configuration that involves as a functional unit, all the musculature of the speech organ. Any disturbance of this neuromuscular configuration as a result of the weakness, paralysis or in co-ordination of the speech musculature or as a result of lesions in the nerves supplying the musculature, results in speech dysfunctions.

Research background with respect to application of acoustic analysis to development of neuro-motor control in children's speech have shown that the following parameters of voice tend to index developmental changes in anatomy, motor control and phonological function ;

i. Vocal fundamental frequency (Fo)
ii. Static formant patterns of vocalic sounds.
iii. Timing and co-ordination of articulation.

Based on this premise, the present study aims at investigating whether certain parameters of voice would be sensitive to index maturational delay or abnormality in neuromotor control of the speech mechanism in development disorders Like cerebral palsy, mental retardation, autism and hearing impairment. This study also aims at finding if certain parameters of voice would enable differential diagnosis of the above developmental disorders in which speech-language retardation is seen. . -

Following are the parameters chosen for the study as these parameters have been found to be useful for differential diagnosis of voice disorders.

I. Frequency parameters :

1. Average fundamental frequency (Fo)
2. Average pitch period (To)
3. Highest fundamental frequency (Hfi)
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 percentage (jitt)
10. Relative average perturbation quotient (RAP)
11. Pitch perturbation quotent (PPQ)
12. Smoothed pitch perturbation quotient (APPQ)
13. Fundamental frequency variation (vFo)
14. Fo tremor intensity index (FTRI)

II. Intensity parameters

1. Shimmer in dB (ShdB)
2. Shimmer in percent (Shim)
3. Amplitude perturbation quotient (APQ)
4. Smoothed amplitude perturbation quotient (SAPQ)
5. Peak amplitude variation (vAM)
6. Amplitude tremor intensity index (ATRI)

HI. Other parameters:

1. Noise to harmonic ratio (NHR)
2. Voice turbulence index (VTI)
3. Soft phonation index (SPI)
4. Degree of voice breaks (DVB)
5. Degree of subharmonic breaks (DSH)
6. Degree of unvoiced segments (DUV)
7. Number of voice breaks (NVB)
8. Number of sub-harmonic segements (NSH)
9. Number of unvoiced segments (NUV)

The review of literature that follows would show the importance of these parameters in understanding the dynamics of normal speech and voice findings in the developmental disorders chosen for the study. Effort has been made to see if there is a trend shown by certain parameters to index delay in maturation the vocal tract or lack of neuromotor control on speech.

Fundamental frequency

Pitch, loudness and quality are the three attributes of voice. Voice and its disorders are described most often using these attributes. Anderson (1961) opines that "both quality, loudness of voice mainly depend upon the frequency of vibration. Hence it seems apparent that frequency is an important parameter of voice"

Pitch is the psychophysical correlate 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 Davis (1935), depends upon the frequency of its dominent component, ie., the fundamental frequency in a complex tone. Fo is the lowest frequency that occurs in the spectrum of a complex tone. In voice also, the fundamental frequency is the lowest frequency in the voice spectrum. This keeps varying depending upon several factors. 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 vocal 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.

Larynx is capable of producing a wide range of fundamental frequencies (Fo) i.e., the vocal cords will be set into vibration at the different frequencies. The larynx has been found to produce Fo ranging from 60 Hz to 2000 Hz (Luschinger and Arnold, 1965).

The physical basis of pitch i.e, fundamental frequency of a periodic tone is relatively easy to quantify and measure. (Hirano, 1981).

There are various objective methods to evaluate the fundamental frequency of the vocal cords. Stroboscopic procedures, high speed cinematagraphy, electroglottography, ultrasonic recordings, stroboscopic, laminography (STROL), Cepstrum pitch detection, digi pitch, the 3m plastiform magnetic tape receiver, spectrography, pitch computer, the high resolution signal analyser frequency meter, visipitch, vocal-II, computer with speech interface unit and softwareietc.

The changes in voice with age in individuals have been of interest to scientists. Various investigations dating back to 1939 have provided data on various attributes at successive developmental stages from infancy to old age. Fairbanks et.**al** 1949), Curry (1940), Snidecor (1943), Mysak (1959), Samuel (1973), Usha Abram (1978), Gopal (1980), Indira (1982), Kushalraj (1983), Rashmi (1985) are some among those who have studied the changes in fundamental frequency of voice with age. The aging trend for males with respect to the mean fundamental frequency is one of a progressive lowering of pitch level from infancy through middle age followed by a progressive raise in the old age (Mysak, 1966). However, in females, among the mean fundamental frequency levels of the 7 and 8 year olds, 8 year olds was the highest. A progressive lowering of fundamental frequency level is then seen till the age of a young adult female. No significant change is seen from young adulthood to the aged group which is in contrast to the male population (Mysak, 1966).

The voice of a new born has been found to be around 400 Hz (Indira, 1982). The fundamental frequency drops slightly during the first three weeks or so, but then increases until about the fourth month of Life, after which it stabilizes for a period of approximately five months. Beginning with the first year, fundamental frequency decreases sharply until about three years of age, when it makes a more gradual decline, reaching to the onset of puberty at 11 or 12 years of age. A sex difference is apparent by the age of thirteen years, which marks the beginning of a substantial drop male voices, the well known adolescent voice change in the case of females. The decrement in fundamental frequency from infancy to adulthood among females is somewhat in excess of an octave, whereas males exhibit an overall decrease approaching two octaves (Kent, 1976).

Lowering in the fundamental frequency is gradual till the age of 10 years (GopaL 1980), 15 years (Samuel, 1973), 13 years (Usha, 1978), 14 years (Rashmi, 1985), after which there is a sudden marked lowering in the fundamental frequency. The fundamental frequency values are distinguished by sex only after the age of 11 years, although small sex differences might occur before the age Kent (1976). Usha (1978), Gopal (1980).

Eguchi and Hirsh (1969) state that "It is well known that the fundamental frequencies of children and adult females are higher than those of the adult male". They further add that "Chidren have a fundamental frequency of about 300 Hz even upto the age of 8 and 10 years. There is no significant difference if fundamental frequency of speech between 7 and 8 years, or between boys and girls of those ages (Fairbanks, Wiley and Bassman, 1949; Potter and Steinberg, 1950; Peterson and Barney 1952).

Gopal (1980) reported a gradual lowering of the fundamental frequency as a function of age from the age of 7 years to 17 years for the vowel |a | in both males and females. Upto puberty there is little difference between the voice of boys and girls. The voice change is prominent at puberty. In majority of the cases this change takes place without appreciable pitch breaks during speech. But in some, a period of pitch breaks are observed due to the inability of the individual to control the laryngeal muscles because of sudden changes in the larynx due to growth. Pitch breaks, however, have been observed in the children, long before the onset of puberty. In an examination of sixty children between the ages of seven and eight years, Fairbanks (1959), could find pitch breaks in both sexes.

Therefore, the voice changes in puberty should be interpreted as the intensification of a process that begins already at a much earlier period (Broadnitz, 1959). The ages of most rapid change in Fo are the first four months, the period of one to three years, and the period of (13 - 17) years. Little change in the mean Fo occurs during the period of three to five years, which Negus (1962) identified as an interval of rapid laryngeal growth. Kaplan (1960; also noted that laiyngeal growth occurs primarily durirnthe first three years and during puberty. Possibily, the age - related differences in mean Fo are caused as much by variations in the vocalization activities as by anatomical and physiological maturation.

Studies on the 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 frequency, which is attributable to the changes in the vocal apparatus at puberty. In the case of females, a gradual lowering of fundamental frequency is seen (Usha, 1979; Gopal, 1980; Kushal Raj, 1983).

Peterson et.al (1985) have investigated voice using multivariable statistical analysis of various parameters of voice as related to puberty in choir boys. They selected 48 boys age ranging from 8-10 years. The results of this statistical analysis depicted that Sexual Hormone Binding globulin (SHBG) is a predictive factor of the change in Fo from childhood to adulthood voice in boys.

Thus, the lowering of fundamental frequency is seen both in case of males and females with age. and these variations are attributed to the anatomical and physiological changes with age. The study of fundamental frequency odiously has clinical implications. Cooper (1974) used spectrographic analysis, as a clinical tool to determine and compare the fundamental frequency in dysphonics before and after vocal rehabilitation. Shantha (1973) and Jayaram (1975) found a significant difference in habitual frequency measures between normals and dysphonics.

It is apparent that measurement of the fundamental frequency is important in the diagnosis and the treatment of voice disorders and also reflects the neuromuscular development in children (Kent , 1976).

As far as the variability of Fo is concerned, the most extensive study is that of Eguchi and Hirsh (1969) from which one conclusion is pertinent: intrasubject standard deviations for the Fo measurements progressively decreased with age until a minimum was reached about 10 - 12 years. If the standard deviations are considered 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 seven to nine years. The discovery that Fo variability diminishes with age has important implications for the quantitative investigation of speech development.

Rutherford (1944) studied voice characteristics: (loudness, pitch and quality), rate and rhythm of speech of cerebral palsied and attempted to differentiate between athetotic and spastic groups of cerebral palsy children. It was found that there was no clear-cut separate entity as cerebral palsied speech that was particularly characteristic of the group. Duffey (1958) revealed that athetoid had a faster reading rate, higher pitch, larger pitch range and faster rate of pitch change than spastic cerebral palsy.

Clement and Twitchell (1959) studied dysarthria in cerebral palsy children in terms of deficits in phonation, respiration and articulation in this pathological group and suggested a physiological interpretation of the deficit. The spastic dysarthrics (quadreplegic group) in terms of phonation, was characterized by high pitch, monotone, weak intensity, breathy quality with abnormal nasal resonance and broken phonation. Athetoids were characterized by a low pitch, sudden uncontrolled rising inflection, weak, forced and varying intensity, throaty quality with large amount of pharyngeal resonance. Spastics had low pitched, loud voice with hoarseness and athetoids showed extreme variation in pitch, varying loudness and harsh quality of voice. Farmer and Lencione (1977) analyzed spectrographically and phonetically extraneous vocal behaviour in 14 cerebral palsied speakers (9 subjects were athetotic and 5 predominantly spastic) aged 8 - 44 years. 71% of subjects demonstrated pre-vocalizations. Wit et al. (1993) studied three non-invasive maximum performance task (MPT), i.e., maximum sound prolongation, fundamental frequency range and maximum repetition rate in 11 spastic cerebral palsied children (age 6.4 - 11.10 years). The mean Fo minimum was found to be higher for the dysarthric group than for the control group. The mean Fo maximum was lower for the dysarthric group than for the control group, yielding a more restricted Fo range (FFR) for the dysarthric group. In the Indian context study done by Riza (1998) showed no significant differences between normal subjects and cerebral palsied subjects in terms of average fundamental frequency.

Strazulla (1953) and Benda (1949) found "low pitched voice" as one characteristic feature of mongolism. Children with mongolism had substantially lower voice than those of normal children.

One frequently noted vocal characteristic of the autistic child is a consistent high pitch often described bird like (Goldfarb et.al, 1956; Pronovost et al.,1966; Goldfarb et al, 1972), have noted excessively high pitch levels with insufficient pitch changes. Pronovost and his associates analysed by DSPsonograph one child's high pitched vocalization and determined a fundamental frequency of 2,500 Hz (Pronovost et.al, 1966)

Several investigators have noted that deaf speakers have a relatively high average pitch or tendency to speak in falsetto voice (Angelocci, Kopp and

Holbrook, 1964; Boone, 1966; Engleberg, 1962; Martony, 1968), which suggest not only that fundamental frequency of deaf are higher than that of hearing impaired speakers on the average, but also that the average fundamental frequency for different speakers span of wider range. Deaf speakers tend to vary the pitch much less than do hearing speakers and the resulting speech has been described as flat or monotone (Calvert, 1962; Hood, 1966; Mortony, 1968).

Gilbert (1975) reported a variety of airflow patterns and air pressure patterns were identified as being characteristic of speech of hearing-impaired individuals. Holbrook and Crowford (1970) and Boone (1966) found that hearing-impaired individuals exhibited higher than normal fundamental frequency values, while Thornton(1964) reported essentially normal speaking frequencies for the hearing-impaired speakers.

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.

Fundamental Frequency in Speech :

Many investigators have studied the speaking fundamental frequency as a function of age and its various pathological conditions. Michel, Hollien and Moore (1965) studied the speaking fundamental frequency characteristics of 15, 16 and 17 year old girls, in order to determine the age at which adult female speaking fundamental frequencies are established. Their results indicated that females attain adult speaking fundamental frequencies by fifteen years of age. It seems necessary, therefore, to study the girls fourteen years of age and younger, in order to determine when adult frequencies are first evidenced (MicheL Hollien and Moore, 1965).

Kushal Raj (1983) studied the speaking fundamental frequencies as a function of age, in children between four and twelve years. He reported that the fundamental frequency, both in the case of males and females, decreases with age, males showing a sudden decrease around eleven years of age. No significant difference in fundamental frequency was found until the age of eleven years, between males and females. The fundamental frequencies of the vowels |a|, |i|, |u|, |e| and |o|, occurring in speech, indicated that the fundamental frequency of vowel |a| was the lowest in both males and females, |u| was the highest for males and |i|, the highest for females.

The age dependent variations of mean speaking fundamental frequency reported by Bohme and Hecker (1970) indicate that the mean speaking fundamental frequency, decreases with age upto the end of adolescence. A marked lowering takes place during adolescence in men. In advanced age, mean speaking fundamental frequency becomes higher in men but is slightK" lowered in women.

Michel and Wendahl (197() studied the developmental trends in vocal fundamental frequency 14 young children between the age of 11 to 25 months, an age period characterised by changes in physiological and linguistic development. Subjects were grouped into 3 month age intervals reflecting a continuum of physical development and were audiotape recorded during spontaneous speech productions. Acoustic analysis of average Fo and Fo variability was performed. Fo variability was found to decrease as subject age increased as did segment durations. They - • concluded that when viewed within the overall developmental period and in comparison with data from other studies of younger and older children, average Fo during this age is consistent with a decreasing trend throughout early childhood.

Sorenson (1989) studied the fundamental frequency characteristics of 30 children between the ages of 6 and 10 years; investigated in a variety of speech tasks. The results indicated that average fundamental frequency across tasks for the boys is approximately 262Hz and for girls approximately 281 Hz. Statistical analysis indicated that there was no significant difference in the Fo of boys and girls in this age range. High vowels were found to have higher Fo values than low vowels, sustained vowels had higher fundamental frequency values than either spontaneous speech or reading for both groups of speakers.

Not much information is available on fundamental frequency in speech of cerebral palsied. Duffy (1958) analysed the speech of cerebral palsied individuals by means of an instantaneous fundamental frequency recorder. The detected pitch characteristics were related to different types of cerebral palsy. Wit et.al, (1993) found that developmental spastic dysarthric children produced shorter sound sequences and more fundamental frequency range. In the Indian context, study done by Riza (1998) showed statistically significant differences when mean fundamental frequency in speech of normals wer£. compared with spastic diplegics as against athetiod quadriplegic.

hi the mentally retarded population the speaking fundamental frequency characteristics of institutionalized mongoloid girls between 8 and 11 years were studied by Hollien and Copeland (1965). Their results showed that mongoloid girls do not exhibit abnormally low speaking fundamental frequency levels but rather possess vocal frequency characteristics generally similar to those of their age peers even though they are retarded with respect to physical size. These results agree with those of Michel and Corney (1964). Contrary to this, Weinberg and Zlatin (1970) reported that the mean speaking fundamental frequency level for the sample of children with mongolism, studied by them, was significantly higher than the mean speaking fundamental frequency level for the control group. In 1974. Montague, Brown and Hollien supported the above findings. Weinberg et.al, (1975) described selected speech characteristics of patients with acromegaly. Some of the patients with acromegaly were found to use a lower fundamental frequency than the normals. This lowering of fundamental frequency was prominent in female acromegalies than in male acromegalies.

Gilbert and Campbell studied the speaking fundamental frequency in three groups (4 to 6 years, 8 to 10 years and 16 to 25 years) of hearing impaired individuals, and reported that the values were higher in the hearing impaired groups when compared to values reported in the literature for normally hearing individuals of the same age and sex.

Fluctuations in frequency and intensity :

Perturbations are defined as the cycle to cycle variations in period and amplitude. Hollien, Michel and Doherty (1973) sustained vowels, obtained mesures of frequency perturbation similar to those of Liberman (1961) which they called the jitter factor. This jitter factor (JF) was defined as the cycle-to-cycle period variations relative to the average speaking fundamental frequency. They suggested that when vocalization other than sustained phonation is used to examine the cycle-to-cycle variations in period, the perturbations may possibly be due to involuntary and/or learned phonatory behaviour associated with meaningful speech patterns produced by the speakers. As sustained phonation reduces the variability due to learned speech patterns and eliminates the differential loading on the glottis related to changes in vocal tract configuration, a more valid assessment of the frequency perturbations associated with laryngeal beha\iour may be obtained using only sustained phonation. Horii (1979) further cautions against the use of connected speech due to the random perturbation associated with "mechano-physiologic" limitations of the glottal source which may accompany such samples. However, Hammarberg et.aL (1980) analyzed the amplitude and period variations that occur in connected speech and obtained a representative samples of voice qualities.

Baer (1980) explains vocal jitter as inherent to the method of muscle excitation based on the neuromuscular models of the fundamental frequency . and muscle physiology. He has tested his model using EMG,from cricothyoid muscle and voice signals and claims neuromuscular activity as the major contributor for the occurance of perturbation. Wyke (1969), Sorenson. Horii and Leonard (1980) have reported the possible role of laryngeal mucosal reflex mechanism in Fo 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 in sustained phonation (Sorenson et al., 1930).

Heiberger and Horii (1982) also says that the mucosal reception in the larynx is important in maintaining the laiyngeal 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, hi addition turbulent air flow at the glottis also causes some perturbation. Limitations of laryngeal neuro mechanism through the articular mucosal reflex system (Gould and Okamura, 1994; Wyke, 1967) may also introduce small perturbation in laryngeal muscle tone. Even without consideration of 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:

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

Where ,

$T_0^{(i)}$, i = 1.2 . . . . . N extracted pitch period data.

N = PER, Number of extracted pitch periods.

2. Jitter per unit or jitt:

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

Where,

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

3. Pitch period perturbation quotient (%):

$$PPQ = \frac{\frac{1}{N-4}\sum_{i=1}^{N-4} \left| \frac{1}{5}\sum_{r=0}^{4} T_0^{(i+r)} - T_0^{(i+2)} \right|}{\frac{1}{N}\sum_{i=1}^{N} T_0^{(i)}}$$

Where :

* ° , i = 1.2,. . . ., N extracted pitch period data
N = PER, Number of extracted pitch periods.

4. Smoothed pitch period perturbation quotient (%)

$$PPQ = \frac{\frac{1}{N-SF+1}\sum_{i=1}^{N-SF+1} \left| \frac{1}{SF}\sum_{r=0}^{SF-1} T_0^{(i+r)} - T_0^{(i+m)} \right|}{\frac{1}{N}\sum_{i=1}^{N} T_0^{(i)}}$$

where,

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

5. Co-efficient of Fo variation (%)

$$VFO = \frac{}{\bar{F}_0} \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N} \frac{1}{N}\sum_{i-1}^{N} F_0^{(i)} - F_0^{(i)^2}}}{\frac{1}{N}\sum_{i=1}^{N} F_0^{(i)}}$$

Where,

$$\bar{F}_0 = \frac{1}{N}\sum_{i=1}^{N} F_0^{(i)}$$, and

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

Where.

yd)
*-° , i = 1,2,. . . . N extracted pitch period data
N = PER. Number of extracted pitch periods.

6. Relative average perturbation (%)

$$\frac{\frac{1}{N-2}\sum_{i=2}^{N-1} \frac{T_0^{(i-1)} + T_0^{(i)} + T_0^{(i+1)}}{}}{\frac{1}{N}\sum_{i=1}^{N} T_0^{(i)}} - T_0^{(i)}$$

Where,

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

Liberman (1963) found that pitch perturbations in normal voice never exceeds 5msecs in the steady state portion of sustained vowels. Similar variations in fundamental periodicity of the acoustic wave form have been measured by Fairbanks et .al (1949) Iwata and Vonledon (1970) reported that the 95% confidence limits of pitch perturbations in normal subjects ranged from -0.19 to +0.2 sec.

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. Sorenson and Horii (1983) 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 attribted this difference to Fo. When the Fo increases the percentage of jitter values decreases. Zemlin, (1962) has reported greater jitter values for |a| than |i| and |u| showed lowest value. This was 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 vowels. Wilcox and Horii, (1980) reported that |u| was associated with significantly smaller jitter (0.55%) than ja; and |i| (0.68% and 0.69% respectively).

Many workers have compiled normative data for Shimmer and Jitter, Horii (1979) reported an average shimmer of 0.39 dB for vowels |a|, |i| and |u|. However, in a later study Horii (1980) and Wilcox and Horii (1980) noted Jitter and/or Shimmer differences among different vowels. Wilcox and Horii (1980) found that ju was associated with significantly smaller Jitter (0.55%), than |a| or |i| (0.68% and 0.69% respectively). Studying older subjects, Horii also found both Jitter and Shimmer to be smallest for |u| intermediate for \i\ and greatest for |a|. On the other hand, a trend towards greater Jitter for high vowels than low vowels was reported by Johnson and Michel (1969) who examined twelve English vowels. Zemlin (1962) reported a significantly greater Jitter for ia| than |i|. Horii (1982) found no significant difference in either Shimmer or Jitter values between eight English vowels and obtained an average Jitter value 0.75% and an average Shimmer value of 0.17 dB.

However, in a recent study, Sorenson and Horii (1983) found that Jitter and Shimmer values to differ for the three vowels |a|, \i[and iuj. The mean directional Jitter factor \vas49.3% with a range of 34.6% (men iu;) to 62.7% (women |i|), while the average directional Shimmer factor was 59.7% with a range of 43.5% (men ji|) to 72.6% (women |u|). Directional factors for Shimmer were on the average, 10% higher than directional factors for Jitter. They also reported that for both the groups (men and women), |u! had the highest directional jitter factors, ja| was the lowest and i was intermediate. The vowel [i| had the highest shimmer factor for the men and a: was intermediate. For the women, the results of these two vowels were reversed. Sorensen and Horii, (1983) studied the vocal jitter during sustained phonation of |a|, |i| and |u vowels. The result showed that jitter values were low for a with 0.71% high for |i| with 0.96% and intermediate for |u| with -0.86%.

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

Research has shown that the intensity, the fundamental frequency level and the type of phonatory initiation and termination are some factors which affect the jitter magnitude in sustained phonation (Moore and Von Leden, 1958; Jacob, 1968 Koike, 1973; Hollien et.al, 1973). Koike (1973) observed differences in the perturbation values for the initiations of the vowel (soft versus breathy) and suggested that different mechanisms are responsible for the two onsets. Cycle to cycle variation of amplitude is called intensity perturbation 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 ShdB:

$$\text{ShdB} = \frac{1}{N-1} \sum_{i=1}^{N-1} 20 \log \left(A^{(i+1)} / A^{(i)} \right)$$

Where,

$A^{(i)}$, I = 1.2,. . . ., N extracted peak to peak amplitude data.

N= Number of extracted impulses.

2. Shimmer percent (%) **or shim** :

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

WTiere,

A^-% I = 1.2.. . . ., N extracted peak to peak amplitude data.

N= Number of extracted impulses.

3. Amplitude perturbation quotient (%) **- APQ:**

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

Where,

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

N= Number of extracted impulses.

4. Smoothed amplitude perturbation quotient (SAPQ)

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

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** :

$$SAPQ = \frac{\frac{1}{N}\underset{i=1}{\overset{N}{\varepsilon}}\frac{1}{N}\sum_{j=1}^{N}A(j) - A^{(i)2}}{\frac{1}{2}\sum_{i=1}^{N}A^{(i)}}$$

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 at least upon the model frequency level, the total frequency range and the SPL relative to each individual voice. Michel 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. Kitajima and Gould (1976) studied the vocal shimmer during sustained phonation in normal subjects and patients with larygeal polyps. They found the value of vocal shimmer ranging from 0.04 to 0.21 dB in normals and from 2.5% to 3.23 dcB in the case of vocal polyps. Although, some overlap between the two groups was observed they noted that the measured value may be an useful index in screening for laryngeal disorders or for diagnosis of such disorders and differentiation between the two groups.

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 (1982,.

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.

Liberman (1961, 1969) has shown that pathological voices generally have large perturbation factors than normal voices with comparable fundamental frequency and that this factor is sensitive to site and location of growths in larynx. Pitch perturbation factor was defined as the relative frequency of occuance of perturbation larger than 0.5 msec. Kitajima and Gould (1976) have found that vocal shimmer is a useful parameter for the differentiation of normals and vocal cord polyp groups. 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 across sessions, while directional perturbation factor was a more temporarily stable measure.

Horii (198:2) found a significant correlation between shimmer and jitter supporting the notion that similar sets of physical forces (such as vocal fold tension, mass length and subglottal pressure) underline the regulation of the individual fundamental period and intensity of laryngeal sounds. In addition, jitter and shimmer has been applied to the early detection of laryngeal pathology (Lieberman 1961; 1963), defined pitch perturbation as the difference in periods of adjacent glottal pulse and suggested that what he termed "the pitch perturbation factor", that is, the percentage of discrete perturbation exceeding 0.5 msec, might be a useful index in detecting a number of laryngeal diseases.

Hecker and Kruel (1971) suggestd that there might be, in addition to the pitch perturbation factor, a "directional perturbation factor", which he defined as the algerbraic sign, or rate of progression, rather than simply the absolute magnitude of difference bertween glottal periods. Applying this criterion, he reported a significantly higher "directional perturbation factor" in pathologic speakers than those in normal speakers. The magnitudinal perturbation factor of Lieberman, on the other hand did not differentiate the two conditions. However, Koike (1973) obtained lower mean magnitude perturbation in normal voices than in pathologic voices.

Koike (1969) showed that a relatively slow period modulation of vowel amplitude was observed in patients with laryngeal neoplasms. He reasoned from this that the measurement and analysis of such modulation might be useful in assessing laryngeal pathology. Crystal and Jackson (1970) measured both the fundamental frequency and amplitude perturbation of voices in persons with varying laryngeal conditions and concluded that several purely statistical measures of the data they extracted might be useful as guidelines in detecting laryngeal dysfunction. Koike (1973) investigated the pitch periods of voice produced by pathologic speakers, and found that discrimination between laryngeal tumor and laryngeal-paralysis was possible. The perturbation factors, both directional and magnitudinal, during sustained vowels, are significant in discriminating normal talkers from those with laryngeal cancer (Murry and Doherty, 1980).

Von Leden and Koike (1970) found a significant correlation between subjects with various laryngeal diseases (Laryngitis, edema, myasthenia laryngis, bilateral adductor paralysis, unilateral paralysis, nodule, hematoma, cyst granuloma benign neoplasms, multiple papilloma, intrinsic and extrinsic carcinoma, senile, spastic and psychosomatic dysphonia) and different types of amplitude modulations and affirmed the potential value of short-term perturbations in the acoustic signal for diagnostic purposes. Their data suggested four different types of amplitude modulations, which in turn correlates with clinical groupings. Kitajima and Gould (1976) studied the vocal shimmer during sustained phonation in normal subjects and patients with laryngeal polyps and found the values of vocal shimmer to range from 0.04 dB to 0.21 dB in normals and from 0.8 dB to 3.23 dB in the case of vocal polyps. Although some overlap between the two groups was observed, they noted that the measured value may be a useful index in screening for laryngeal disorders or for diagnosis of such disorders and differentiation between the two groups.

Sorenson, Horii and Leonard (1980) pointed out that the average jitter was significantly greater under anesthesia than under normal conditions, and that the jitter difference was more prominent at high frequency phonation, indicating that high frequency phonations are more dependent on laryngeal mucosal feedback.

Smith et al., (1978) analyzed the voice of oesophageal speakers and indicated that the magnitude of vocal jitter present in the vowels was substantially larger than that in normal speakers, and speakers with laryngeal/vocal disturbance.

To-date, relatively few attempts have been made to measure perturbations in fundamental frequency and intensity, in children, although such a measure may have value in describing the stability of laryngeal control (Lieberman, 1963). Basma, Truby and Lind (1965) proposed that an infant's neurological maturity might be evaluated from such factors as the stability of laryngeal co-ordinations and the mobility of vocal tract components during crying. Though information on the cycle-to-cycle variations in fundamental frequency and amplitude as a function age are scant, many investigators have found these measures to be useful in describing the voice characteristics of both normal and pathological speakers (Koike, 1969, 1973; Hollien, Michael and Doherty, 1973; Murry and Doherty, 1980; Horii, 1979, 19S2). This irregularity in vibration has been implicated as a physical correlate of rough or hoarse voices (Bowler, 1964; Coleman, 1969, 1971; Moore and Thomson, 1965; Isshiki 1966; Coleman and Wendahl, 1968; Yanagihara, 1967a,b; Hirano 1971; Deal and Emanuel, 1978).

Considerable caution must be taken in interpreting these data, however, because gross changes in wave periods (upto an octave in extent) were reported to be characteristic not only of pathologic voice but also of vocal recordings taken from adolescent boys and girls, preadolescent children of both sexes, and from postmenarcheal females (Fairbanks et al., 1949; Curry, 1940; Duffy, 1958). The fluctuations in frequency and intensity in a given phonation sample may indicate the physiological (Neuromuscular) or pathological changes in the vocal mechanism. In cerebral palsy, Palmer suggests that laryngeal block might interfere with phonation and he calls attention to the proper functioning of intrinsic laryngeal structure in cousumating the delicate adjustment of the vocal cords for satisfactory glottal vocal attach for speaking.

Not much information regarding frequency and intensity fluctuation in cerebral palsied individuals is available. Riza (1998) studied voice of cerebral palsied childrenin age range (3 - 10) years and found satisfactory significant differences between normal counterparts in terms of speed and extent of fluctuation in both frequency and intensity. No literature is availble in the autistic, mentally retarded or hearing impaired group on perturbation measures.

The multidimensional analysis of voice (MDVP) software has been used to find normative data, however, no studies have been done across abnormal populations. Anitha (1994) established a relationship between the various acoustic parameters of voice and also created a data base as well as normative data using software and voice disorders could be clearly deleneated. Thus it is seen from review of literature that investigations have carried out studies regarding various parameters of voice in normal children and a few attempts in the disordered populations.

This study has been undertaken to see if certain parameters of voice could indicate a maturational delay in neuromotor speech control and if they could be used to differentially diagnose between developmental disorders in the light of the existing premise that voice parameters do index the maturation of the vocal tract or neuro-motor speech control.

METHODOLOGY

This study was undertaken to identify the parameters of voice that could indicate abnormality in neuromotor speech control. This study also aimed at examining efficiency of these parameters of voice for differential diagnosis between developmental disorders in the light of the existing premise that voice parameters index the maturation of the vocal tract. It was decided to consider the following acoustic parameters in analysing the voice of the developmental disorders of cerebral palsy, mental retardation, autism and hearing impairment.

These voice parameters were chosen as they have been found useful in differentiating between normal and abnormal voice using the multidimensional analysis of voice programme developed and marked by Key Elemetrics Inc., New Jersey.

Frequency Parameters :

1. Average fundamental frequency (F_o)
2. Average pitch period (T_o)
3. Highest fundamental frequency (Fhi)
4. Lowest fundamental frequency (Flo)
5. Standard deviation of fundamental frequency (STD)
6. F_o tremor frequency (Fftr)
7. Amplitude tremor frequency (Fatr)
8. Absolute Jitter (Jita)
9. Jitter percentage (Jitt)
10. Relative average perturbation quotient (RAP)
11. Pitch period perturbation quotient (PPQ)
12. Smoothed pitch period perturbation quotient (SPPQ)
13. Frequency tremor intensity index (FTRI)
14. Fundamental frequency variation (vF_0)

II. Intensity parameters :

1. Shimmer in dB (ShdB)
2. Shimmer percent (Shim)
3. Amplitude perturbation quotient (APQ)
4. Smoothed amplitude perturbation quotient (SAPQ)
5. Peak amplitude variation (Vam)
6. Amplitude tremor intensity index (ATRI)

HI. Other parameters :

1. Noise to harmonic ratio (NHR)
2. Voice turbulence index (VTI)
3. Soft phonation index (SPI)
4. Degree of voice breaks (DVB)
5. Degree of subharmonic segments (DSH)
6. Degree of unvoiced segments (DUV)
7. Number of voice breaks (NVB)
8. Number of sub-harmonic segments (NSH)
9. Number of unvoiced segments (NUV)

Subjects :

A total of four spastic cerebral palsied (three males and one female) age ranging from (4 - 13) years, four mentally retarded males ranging in severity from mild to moderate degree with age ranging from (7 - 12) years, six autistics, (four males and two females) age ranging (14 - 16) years, six hearing impaired ranging in severity from severe to profound, age ranging (4 - 9) years, all with delayed speech and language were chosen as the experimental groups for the study. These diagnosis were based on examination by qualified speech and language pathologists and audiologists. Reports of psychological and otorhinolaryngological evaluations and reports provided by the neurologist and the physiotherapist also served as additional basis for diagnosis.

Subjects were randomly selected from the therapy clinic of All India Institute of Speech and Hearing, Mysore. Criteria for selection were that the subjects :

1. having no multiple handicap.
2. having no associated hearing handicap (subjects other than those exclusively hearing impaired)
3. having no associated visual inacuity.
4. No linguistic restriction (subjects having Malayalam or Kannada as mother tongue were chosen).
5. Age ranging from (4 - 16) years.

Age and sex matched subjects who were examined by a speech language pathologist and who were considered normal in terms of speech, language and hearing, who were attending normal regular school served as normal controls.

Diagnosis of subjects	SL No.	Age (Years)	Sex(M, F)
Delayed Speech and Language with Cerebral Palsy.	1.	4	**M**
	2	5.3	**M**
	3	11	**M**
	4.	13.6	F
Delayed Speech and Language with Mental Retardation.	1.	7	**M**
	2.	10.6	**M**
	3.	12	**M**
	4.	13	**M**

Diagnosis of subjects	**SL No.**	**Age (Years)**	Sex(M, F)
Delayed Speech and Language with Autism.	**1.**	**4**	M
	2.	**8**	M
	3.	9	M
	4.	15	M
	5.	**11**	F
	6.	13	F
Delayed Speech and Language with Hearing Loss.	**1.**	4.2	M
	2.	5.6	M
		9	**M**
	4.	10	M
	5.	**4**	F
	6.	5.3	F

Test Material:

Picture cards, toys and any item of interest to the child were used to elicit phonation samples.

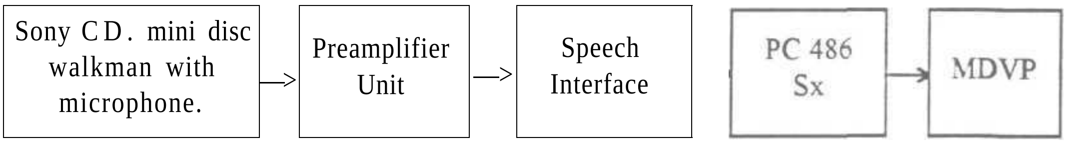
Test environment

Recording was carried out within the therapy sessions for subjects who were not co-operative to be taken to the recording unit at the Speech Science Lab, All India Institute of Speech and Hearing. Subjects were seated comfortably with the therapist, caretaker and siblings if present. A stimulating environment with toys, picture books and any object of interest to the child were provided to elicit voice samples.

The microphone was allowed to be handled by the child.

Instrumentation

1. Sony CD. mini disc walkman with Sony microphone.
2. Mini disc cassette (Digital audio tape - 3M, 4 mm data tape, DDS - 90?
3. Pre amplifier.
4. CSL speech interface unit-model 4300B.
5. Computer with Pentium.
6. 486 Sx with CSL 50 hardware card.
7. MDVP software.
8. Jack connecting line out of CD. walkman to input on CS.L. SIU.



The voice samples recorded in the digital audio tape was fed into the speech interface unit. The duration of each voice sample used for analysis was 2-3 secs. The sample was digitized at a rate of 50,000 Hz.

Procedure

Microphone was kept at 4 - 6 inches as much as possible from the subjects mouth.

Modelling and imitation techniques of stimulation involving the caretakers and siblings in addition to the therapist were used to ehcit the phonation sample.

Picture cards, toys or any other item interesting to the child was used to stimulate the child to phonate the vowels |a|, |i| and |u|.

Demonstration was carried out by the investigator until the subjects could at least partially understand what response was expected.

A minimum of three trials were allowed and more if needed before the subject satisfactorily phonated the vowels. Three trials were recorded.

DATA ACQUISITION AND ANALYSIS 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 or 'set' for running speech".

↓

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.

Analysis : The best voice sample of the three trials recorded were analysed using the MDVP software. Results of the analysis, i.e., display of the results were obtained for the four disordered populations; cerebral palsy, mental retardation, autism and hearing impairment and their age and sex matched controls.

Data was tabulated and further subjected to statistical analysis using the SPSS software to obtain descriptive statistics as well as inferential statistical information (Wilcoxon's Rank Signed non parametric test).

RESULTS AND DISCUSSION

The purpose of the present study was to find out the differences in **the** acoustic parameters of voice between the developmental disordered populations (cerebral palsied, mentally retarded, autistic, hearing impaired) and normal control subjects in the age range of (8 - 16) years, and to identify the parameters which would help in differentiating abnormal from normal children.

For this purpose it was decided to :

*compare values obtained by normal male and female subjects with **the** cerebral palsied, mentally retarded,autistic and hearing impaired groups wherever obtained.

*Compare the values between normals and each disorder as a group.

* Compare values between the normals and abnormal group as a whole.

The significance of difference between groups have been determined using Wilcoxon signed ranks test. A total of 29 parameters measured using **the** multidimensional voice profile program (Kay Elemetrics Inc., New Jersey) were compared bertween the normals and developmental disordered groups.

Frequency Parameters :

1. Average Fundamental Frequency (Fo)

The mean and standard deviation values of average fundamental frequency in both normal subjects (controls) and subjects of developmental speech and language disordered populations of cerebal palsy,mentally retarded, autisjn, hearing impaired are shown in Tables - I(a) and I(b).

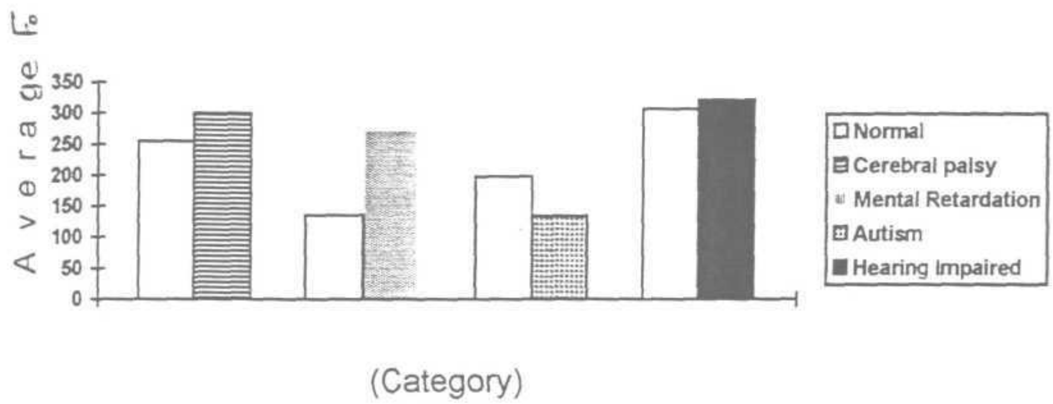
TABLE - I (a) : Mean and SD values of Average Fundamental Frequency (Fo) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels |a|, |i| and |u.

Category (MF)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M)	232.08	291.15	261.61	(34.22)	(26.79)	(10.79)	+	+	+
Cerebral Palsv (M)	326.10	339.67	327.64	(31.89)	(22.37)	(11.79)			
Normal (M)	232.84	247.26	261.43	(6.82)	(7.68)	(18.09)	-	+	+
Mental Retardation (M)	290.00	306.00	324.78	(13.07)	9.43)	(16.36)			j
Normal (M)	267.74	282.06	282.06	(47.12)	(60.61)	(57.51)	-	-	-
Autism (M)	282.46	264.76	294.28	(39.79)	(54.28)	(63.20)			
Normal (F)	301.30	279.17	261.96	(15.09)	(25.98)	(42.89)		-	- i
Autism (F)	245.14	248.75	262.96	(38.53)	(43.83)	(42.84)			
Normal (M)	282.78	296.33	310.06	(17.84)	(34.20)	(33.60)	-	-	-
Hearing Impaired (M)	273.08	314.16	363.38	(34.85)	(38.83)	(34.14)			
Normal (F)	318.21	333.08	310.06	(8.82)	(9.10)	(30.59)	-	-	- \
Hearing Impaired (F)	369.33	418.00	363.38	(22.97)	(26.37)	(34.15)			

TABLE - I(b) : Mean and SD values of Average Fundamental frequency in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	S.D.	Significance
Normal (Ctrl)	255.34	56.31	-
Cerebral Palsy (Exp)	300.08	75.84	
Normal (Ctrl)	135.26	68.88	+
Mental Retardation (Exp)	274.04	19.11	
Normal (Ctrl)	197.76	85.65	-
Autism (Exp)	133.97	43.34	

Category	Mean	S.D.	Significance
Normal (Ctrl)	306.81	28.86	-
Hearing Impaired (Exp)	321.61	61.66	
Total of Normal group	276.82	57.79	-
Total of Experimental Group	298.45	65.69	



Normal controls of respective abnormal populations

Graph -I : Comparison of Normals vs Dvelopmental Seech and Language disordered groups in terms of Average Fundamental frequency.

It was seen from the Tables - I(a) and I(b) that the mean average Fo scores for |aj, i and |u| were higher in cerebral palsied group (all males) than in the normal control group, results tending towards significant difference (P > 0.05 < 0.06 level).Considering the cerebral palsy group as a whole (males and females together), no significant differences were observed for vowels when compared to normal controls.

The same trend was observed in thegroup of mentally retarded children (all males) when compared to normal group, results tending towards significant difference (P> 0.05 < 0.06 level) for |i| and |u|. Considering the mentally retarded group as a whole, significant group differences (P < 0.05 level) were seen for vowels when compared to normal controls.

On comparison of the normal and autistic groups, it was found that the mean average Fo values for |a| and |u| were slightly higher and slightly lower for |i| than in case of normal males, although results were not found to be significant. In case of female autistic subjects, slightly lower mean average Fo for ia and |i| were observed results tending towards significant difference for |u| (P > 0.05 < 0.06 level). However, no significant group differences were seen for vowels when autistic group as a whole (both males and females) were compared to normal controls.

When compared, the normal and hearing impaired groups (both males and females), it was found that mean average Fo values for iaj, |i| and |u| did not significantly differ between groups however a trend for higher average Fo values could be seen seen in both male and female hearing impaired groups. Considering hearing impaired group as a whole (males and females together) no significant group differences were seen for vowels when compared to normal controls. Significant group differences were not seen when the total normal group was compared to the total of experimental groups. Thus the null hypothesis stating that there is no significant differences between the normals and developmental speech and language disorders of cerebral palsy, mental retardation, autism and hearing impairment in terms of average Fo was rejected. Findings in cerebral palsied population is in support of Clement and Twitchell (1959) who found phonation in dysarthric group of cerebral palsy was characterized by high pitch. Witt, et.al., (1993) also found mean Fo minimum to be higher for the developmental spastic dysarthric than normals. Finding of present study argue against Riza (1998) study, who did not find any significant differences bertween normal subjects and cerebral palsied subjects in terms of average fundamental frequency.

Findings in mentally retarded population could be accounted for by maturational effect. Weinberg and Zlatin (1970) have accounted for higher fundamental frequencyof voice in children in Down's syndrome by saying that if it can be speculated that smaller children may have smaller larynges, then the finding of higher voice Fo in children with Down's syndrome is expected.

Findings in the autistic male subjects is in support of findings of Goldfarb et aL, 1956; Pronovost et.al., 1966; Goldfarb et.al., 1972 who have noted consistent high pitch quality in autistic voice. Simon (1975) has postulated that the high pitch levels that are found in some autistic children may be due to failures in the perception of low frequency sounds. To support this findings in the female autistic subjects, there are no studies reported in literature, however Goldfarb et.al 1956; Pronovost et.al., 1966 have found patterns of whispered echolalia.. This tendency of whispered speech might have lowered the average Fo observed in the female autistic subjects in this study.

The lack of difference between normals and hearing impaired children in fundamental frequency is the same as that found in other studies for 6 to 12 years old children (Boone, 1966; Monson, 1979, Osbergei and McGarr 1982; Aparna 199S). However, tendency for higher average Fo values in hearing impaired (both males and females) when compared to normals can be attributed to the fact that these individuals tend to speak in falsetto voice (Angelocci, et.al., 1964; Boone 1966; Engleberg, 1962; Martony, 1968). Angelocci, Kopp and Holbrook (1964) attribute abrnoaml pitch to efforts they use to differentiate vowels by varying Fo and amplitude, rather than frequency and amplitude of formants. hi physiological terms he is achieving vowel differentiation by excessive laryngeal variation with only minimal articulatory variation. Pickett (1968) says increase in Fo is due to increased subglottal pressure and tension of the vocal folds. He opined increased vocal effort is directed at the laryngeal mechanism for kinesthetic feedback leading to increase in Fo.

Willemain and Lee (1971) hypothesised deaf speakers use extra vocal efiforts to get an awareness of the onset and progress of voicing and this becomes the cause of high pitch. Higher Fo in hearing impaired group has been supported by Jayaprakash (1998), Priya Paul (1998) and Rathna Kumar (1998) in the Indian context. Thus it can be concluded that the developmental disordered groups show a higher average Fo compared to normals.

2. Average pitch period (To):

Tables-II(a) and II(b) shows the mean and standard deviation of average pitch period in both normal subjects and subjects of the developmental speech and language disorderd populations.

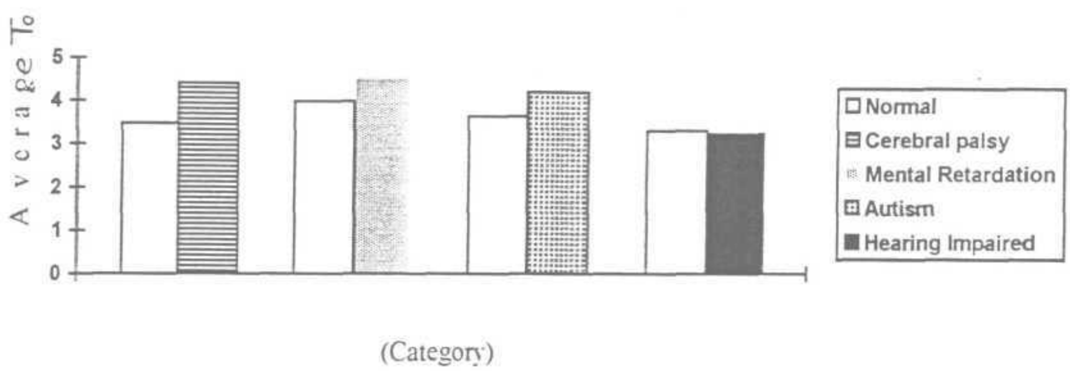
TABLE - ll(a) : Mean and SD values of Average pitch period (To) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels |a|. |i| and |u|.

Category (MJ)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M)	4.82	4.71	4.67	(2.12)	(2.18)	(2.40)			
Cerebral Palsv (M)	3.09	2.96	3.10	(0.30)	(0.19)	(0.12)			
Normal (M)	4.67	4.47	4.45	(1.75)	(1.84)	(1.98)	-	-	-
Mental Retardation (M)	3.46	3.28	3.09	(0.16)	(0.94)	(0.16)			
Normal (M)	3.84	3.69	3.69	(0.81)	(0.89)	(0.87)	-	-	-
Autism (M)	4.38	4.41	4.00	(2.15)	(1.95)	(2.10)			
Normal (F)	3.32	3.60	3.89	(0.17)	(0.34)	(0.66)	+	-	-
Autism (F)	4.14	4.09	3.89	(0.65)	(0.72)	(0.66)			
Normal (M)	3.55	3.43	3.26	(0.23)	(0.41	(0.35)	-	-	-
Hearing Impaired (M)	3.71	3.33	2.85	(0.47)	(0.72)	(0.28)			
Normal (F)	3.14	3.00	3.26	(0.83)	(0.82)	(0.35)	-	-	-
Hearing Impaired (F)	2.73	2.41	2.85	(0.16)	(0.14)	(0.28)			

TABLE - n(b) : Mean and SD values of Average Pitch Period(To) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	S.D.	Significance
Normal (Ctrl)	3.47	(0.78)	-
Cerebral Palsy (Exp)	4.39	(0.51)	

Category	Mean	S.D.	Significance
Normal (Ctrl)	3.98	(0.20)	-
Mental Retardation (Exp)	4.53	(1.68)	
Normal (Ctrl)	3.63	(0.6)	-
Autism (Exp)	4.18	(1.56)	
Normal (Ctrl)	3.29	(0.32)	-
Hearing Impaired (Exp)	3.22	(0.59)	
Total of Normal group	3.86	(1.24)	-
Total of Experimental Group	3.57	(1.05)	



Normal controls of respective abnormal populations

Graph - II : Comparison of Normals vs Developmental Speech Language disordered groups in terms of Average Pitch Period.

It can be seen from the tables- II(a) and II(b) that the mean average pitch period for !a| , |i| and |u| did not significantly differ between normals and the developmental speech and language disorded groups of cerebral palsy, mental retardation autism and hearing impairment. Thus the null hypothesis stating that there is no significant difference in terms of average pitch period (To) between normals and subjects of the developmentally disordered groups of cerebral palsy, mental retardation, autism, hearing impairment has been accepted. Thus it was concluded that the Average Pitch Period is not a useful parameter in differentiating developmental disordered groups from normals.

3. Highest Fundamental Frequency (Fhi) :

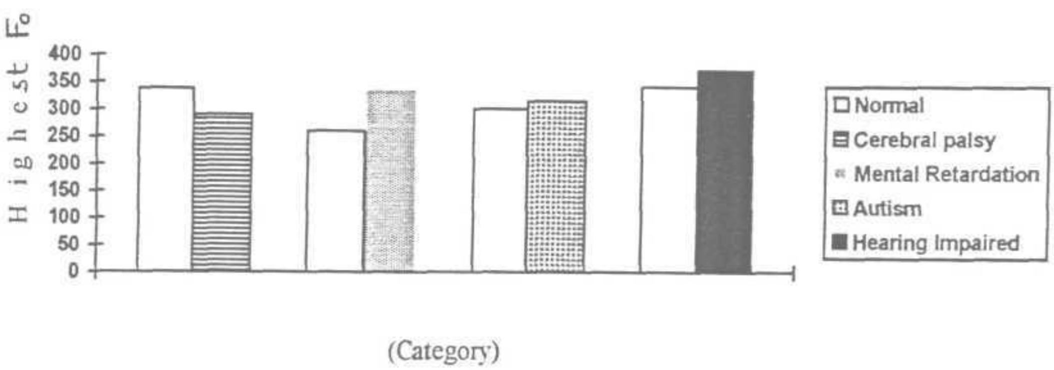
The mean and standard deviation of highest fundamental frequency in both the normal subjects and the developmental speech and language disordered population of cerebral palsy, mental retardation, autism hearing impairment are shown in Tables -III(a) and III(b).

TABLE - III(a) : Mean and SD values of Highest Fundamental Frequency (Fhi) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels iaj, |i| and |u.

Category (M.F)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M)	261.60	253.15	331.99	(35.70)	(40.53)	(28.21)	-	-	-
Cerebral (M) Paisv (M)	350.80	412.68	362.73	(43.57)	(40.68)	(32.31)			
Normal (M)	243.70	269.51	266.82	(27.42)	(20.08)	(21.34)	-	-	-
Menial Retardation (M)	309.36	371.S9	331.84	(14.85)	(19.63)	(16.72)			
Normal (M)	306.12	249.13	249.12	(29.93)	(35.42)	(26.71)	-	-	-
Autism (M)	339.62	281.84	359.27	(22.26)	(43.24)	(44.65)			
Normal (F)	323.75	288.24	307.02	(33.26)	(28.69)	(22.17)	-	-	-
Autism (F)	282.52	273.91	307.02	(31.56)	(50.88)	(22.17)			
Normal (M)	313.75	311.32	375.59	(37.70)	(35.66)	(34.36)	-	-	-
Hearing Impaired (M)	303.38	369.13	396.27	(37.15)	(26.39)	(27.77)			
Normal (F)	343.60	353.74	375.60	(24.81)	(13.62)	(24.32)	-	- -	-
Hearing Impaired (F)	437.64	471.91	395.27	(19.34)	(21.54)	(17.78)			

TABLE - III(b): Mean and SD values of Highest Fundamental Frequency (Fhi) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	S.D.	Significance
Normal (Ctrl)	338.31	(75.40)	-
Cerebral Palsy (Exp)	290.15	(50.26)	
Normal (Ctrl)	260.01	(32.76)	+
Mental Retardation (Exp)	337.70	(55.29)	
Normal (Ctrl)	300.03	(75.00)	-
Autism (Exp)	313.88	(57.00)	
Normal (Ctrl)	339.70	(49.95)	-
Hearing Impaired (Exp)	370.11	(32.07)	
Total of Normal group	301.95	(83.87)	-
Total of Experimental Group	340.40	(84.21)	



Normal controls of respective abnormal populations

Graph -III : Comparison of Normals vs Developmental Speech and Language disordered groups in terms of Highest Fundamental Frequency.

It can be seen from the tables - III(a) and III(b) that the mean Fhi scores for |a|, |i| and |u| were higher in cerebral palsy (all males) when compared to normals, results tending towards significant difference for |i| (P> 0.05 < 0.06). Considering cerebral palsy group as a whole (males and females together) no significant group differences were seen for vowels.

Comparing the mentally retarded group and the normal controls significant group differences were observed for vowels (P < 0.05 level).

On comparing normal and autistic group, it was observed that the above trend was replicated in males, results tending towards significant difference (P > 0.05 < 0.06 level) for |u|. However no significant group difference was seen in the autistic female subjects when compared to normal control subjects.

On comparing the hearing impaired subjects (males and females) with their normal control subjects no significant group differences were seen, however a tendency for higher values for the mean Fhi were observed in both males and females and greater for females when compared to their normal control subjects. Considering the hearing impaired group as a whole (males and females together) no significant group differences were seen for vowels. Considering the total of normal group and experimental groups significant differences were seen from vowels. Thus the null hypothesis stating that there is no significant difference in terms of highest fundamental frequency (Fhi) between normals and the subjects of the developmental speech and language disordered groups of cerebral palsy, mental retardation, autism, hearing impairment has been partially rejected. Therefore, it was concluded that the developmental speech and language disordered groups showed a tendency for higher Fhi values and this parameter could be useful in differentiating the disordered groups from normals.

4. Lowest Fundamental Frequency (Flo):

The mean and standard deviation values of lowest fundamental frequency in both normal subjects and subjects of developmental speech and language disordered population of cerebral palsy, mental retardation, autism hearing impairment are shown in Tables-IV(a) and IV(b).

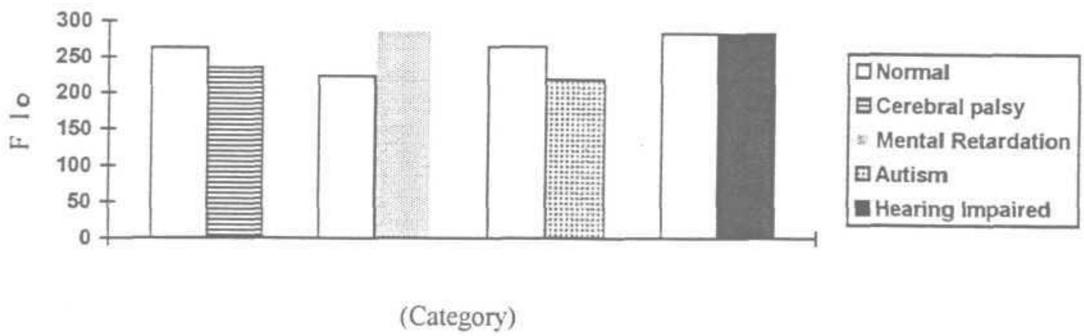
TABLE - IV(a) : Mean and SD values of Lowest Fundamental Frequency (Flo) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels |a|, |i| and |u|.

Category *(MF)*	Mean			S.D.			Sgnificnace		
	a	i	u	a	i	u	a	i	u
Normal (M	213.33	226.82	214.42	(49.37)	(45.04)	(46.19)	-	-	-
Cerebral i\I) Palsy (M)	286.34	294.11	282.61	(42.06)	(41.78)	(38.15)			
Normal (M	225.63	224.77	217.98	(26.05)	(23.88)	(31.04)	-	-	-r
Mental Retardation (M)	271.42	280.98	307.91	(16.19)	(22.11)	(19.90)			
Normal (M	243.66	268.73	268.72	(30.68)	(25.71)	(25.17)	-	-	-
Autism (M	205.09	225.71	212.84	(20.61)	(26.59)	(24.18)			
Normal (F	269.71	269.68	236.51	(18.27)	(21.63)	(22.72)	-	-	-
Autism (FJ	217.56	227.00	236.51	(25.23)	(28.70)	(22.75)			
Normal (M	258.93	279.68	275.42	(21.39)	(35.86)	(37.75)	-	-	-
Hearing Impaired (M)	250.04	278.18	322.95	(32.18)	(29.63)	(30.67)			
Normal (F)	288.57	313.61	275.42	(30.95)	(24.17)	(27.75)	-	-	-
Hearing Impaired *(F*	309.75	362.12	322.95	(19.67)	(19.35)	(19.67)			

TABLE - IV(b): Mean and SD values of Highest Fundamental Frequency (Fhi) in bom normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	S.D.	Significance
Normal (Ctrl)	263.16	(54.14)	-
Cerebral Palsy (Exp)	234.80	(65.99)	
Normal (Ctrl)	222.81	(37.68)	+
Mental Retardation (Exp)	286.77	(22.19)	

Category	Mean	S.D.	Significance
Normal (Ctrl)	263.41	(38.63)	-
Autism (Exp)	218.72	(43.71)	
Normal (Ctrl)	281.76	(30.41)	-
Hearing Impaired (Exp)	281.53	(50.66)	
Total of Normal group	255.07	(53.81)	-
Total of Experimental Group	260.06	(61.61)	



Normal controls of respective abnormal populations

Graph - IV : Comparison of Normals vs Developmental Speech and Language disordered groups in terms of Lowest Fundamental Frequency.

It was seen from the tables - IV(a) and IV(b) that the mean (Flo) scores for ja|, |i| and |u| had a tendency to be higher in cerebral palsy group (all males) compared to the normal control group although results were not significantly different. Considering the cerebral palsy group as a whole (both males and females together) no significant differences were observed for vowels. A similar trend was seen in the mentally retarded (males) when compared to normal control group results tending towards significant difference ($P > 0.05 < 0.06$ level) for |u|. Comparing the mentally retarded group with normals significant differences were seen for vowels at ($P < 0.05$ level).

On comparision the normals and autistic group, it was found that mean (Flo) values for |a|, |i| and |u| showed a tendency to be lower for both males and females separately and when considered together as a whole group.

Regarding the hearing impaired subjects it was found that the mean (Flo) values for |a|, |i| and |u| in both males and females did not significantly differ when compared to normal control subjects, although a slight tendency for higher mean (Flo) values were seen. Considering both males and females as a group no significant differences were seen. Considering the total of normals and the total experimental groups no significant differences were seen.

Thus the null hypothesis stating that there is no significant difference in terms of lowest fundamental frequency (Flo) between the normals and subjects of the developmental speech and language disordered groups of cerebral palsy, mental retardation autism and hearing impairment has been partially rejected. Hence, it was concluded that the Flo was not very useful in differentiating the developmental speech and language disordered groups from normals.

Considering the findings with respect to (Fhi) and (Flo) with respect to cerebral palsy, the findings in the present study are consistent with the study by Witet. al., (1993), who have reported mean Fo minimum to be higher for the developmental spastic dysarthric group when compared to normal control subjects. However, considering the (Fhi), Witet.al.,(1993) have reported that the mean Fo maximum was lower for the developmental spastic dysarthric group than normal control subjects, yielding a more restricted Fo range for the cerebral palsied group. With respect to fundamental frequency range, similar conclusion could be drawn in the cerebral palsy group in this study as the (Flo) also showed a trend for higher values like the (Fhi).

There have been not been many studies reported with respect to fundamental frequency characteristics in mentally retarded. However, present findings with respect to (Fhi) and (Flo) in the mentally retarded do not agree with Strazulla (1953); Benda (1949) who found low pitched voice in mongolism.

Weinberg and Zlatin (1970) also found low speaking fundamental frequency characteristic of mongoloids males and females. The low pitch characteristic of mentally retarded (mongoloids) have not be replicated in the findings of the present study.

Considering the findings in the autistic population, with respect to (Fhi) and (Flo) autistic subjects tendency for high mean (Fhi) may be accounted for by their tendency for whispered echolalic speech as reported by Goldfarb et al, 1956; Pronovost et al., 1966. This tendency for whispering has been viewed as an effort to inhibit echolalic responses, echolalia been present in most of the subjects supports this finding. Findings with regard to low mean (Flo) could be attributed to lack of "emotional tone" and "failure to express personality" reflected in a low (Flo). Restricted pitch variation, results in "flat" or "monotone" voice.

Tendency for higher (Fhi) in hearing impaired supports the findings of Angelocci, et. al 1964. Boone, 1966; Engleberg, 1962 and Martony, 1968, who noted that deaf speakers have a relatively high average pitch, or tendency to speak in falsetto voice.

Slighter higher than normal Mean (Flo) values in the hearing impaired subjects implicates that the ability to vary the pitch is reduced in hearing impaired compared to normals which suggests possible abnormalities in the vocal system. Thus it was concluded that the parameter of highest fundamental frequency (Fhi) could be useful in differentiating developmental speech and language disordered groups from normals.

5.Standard Deviation of Fundamental Frequency (STD):

The mean and standard deviation values of values of STD in both normal subjects and subjects of developmental speech and language disordered populations of cerebral palsy, mental retardation, autism, hearing impairment are shown in Tables-V(a) and V(b).

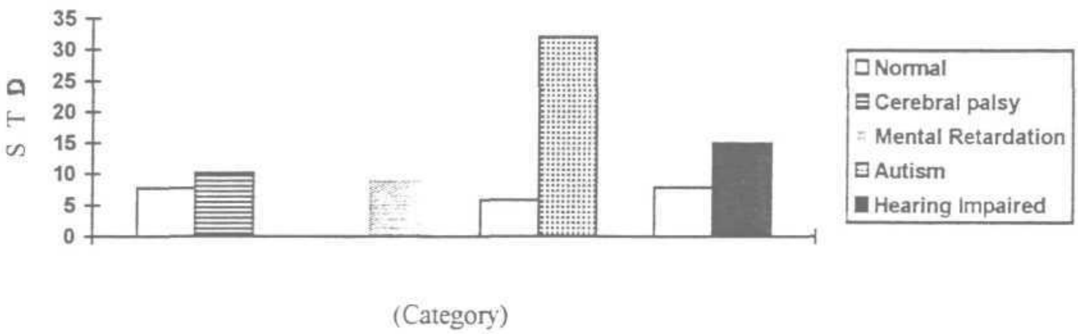
TABLE - V(a) : Mean and SD values of Standard Deviation of Fundamental Frequency (STD) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels |a|, |i| and |u|.

Category (MJ)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M) Cerebral (M) Palsy (M)	5.52 8.95	5.53 13.74	6.73 13.15	(4.15) (4.10)	(3.93) (4.29)	(0.86) (.7.66)	+	+	+
Normal (M) Mental Retardation (M)	2.10 6.84	5.42 9.38	3.11 11.70	(0.67) (3.52)	(2.22) (5.57)	(0.74) (.8.81)	+	+	+
Normal (M) Autism (M)	5.80 25.36	4.41 8.38	4.41 17.67	(3.71) (10.52)	(0.45) (4.51V	(0.83) (5.69)	+	+	+
Normal (F) Autism (F)	5.62 13.21	2.93 8.44	2.85 11.28	(3.81) (1.43)	(0.71) (1.75)	(0.54) (3.54)	+	+	+
Normal (M) Hearing Impaired (M)	5.85 14.71	5.36 13.95	12.25 11.19	(3.63) (3.81)	(2.98) (5.75)	(5.92) (6.80)	4-	+	-
Normal (F) Hearing Impaired (F)	6.12 22.98	5.57 26.45	4.23 21.95	(2.93) (6.93)	(0.57) (7.70)	(1.92) (7.80)	+	+	+

TABLE - V(b) : Mean and SD values of Standard Deviation of Fundamental Frequency (STD) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	S.D.	Significance
Normal (Ctrl) Cerebral Palsy (Exp)	7.74 10.19	(3.68) (5.91)	+
Normal (Ctrl) Mental Retardation (Exp)	3.81 9.31	(1.92) (5.71)	+
Normal (Ctrl) Autism (Exp)	5.82 31.93	(1.65) (18.27)	+

Category	Mean	S.D.	Significance
Normal (Ctrl)	7.79	(3.75)	+
Hearing Impaired (Exp)	14.86	(7.52)	
Total of Normal group	6.39	(2.58)	-
Total of Experimental Group	18.13	(6.03)	



Normal controls of respective abnormal populations

Graph - V : Comparison of Normal vs Developmental Speech and Language disordered groups in terms of Standard Deviation of Fundamental Frequency.

It can be seen from the tables - V(a) and V(b) that the STD scores for |a|, |i| and |u| was higher in the developmental speech and language disordered groups (cerebral palsy, mental retardation, autism and hearing impairments) when compared to each of their normal control subjects, results tending towards significant (P > 0.05 < 0.06 level) and results significant for vowels at P < 0.05 level when each of the disordered groups (males and females together) were compared to normals. The total of experimental groups as a whole when compared to normal controls showed significant differences at P < 0.05 level.

Thus the null hypothesis stating that there is no significant difference in terms of standard deviation of fundamental frequency (STD) between normal subjects and subjects of the developmental speech and language disordered groups (cerebral palsy, mental retardation, autism, hearing impairment) is rejected. Since STD is calculated by extracting the deviation in fundamental frequency during phonation and sentences, an increase in the STD in the discovered groups may be attributed to inability to maintain a constant pitch and intensity during phonation due to abnormality in the vocal system. This variability also indicates a lack of neuromotor maturation and lack of co-ordination between the laryngeal and phonatory systems in the developmental speech and language disordered groups. Thus, it was concluded standard deviation of fundamental frequency is very good parameter in differentiating the developmental speech and language disordered groups from the normals.

6. Fo tremor frequency (Fftr):

The mean and standard deviation values of (Fftr) in both the normal subjects and developmental speech and language disordered groups are presented in Tables - VI(a) and VI(b).

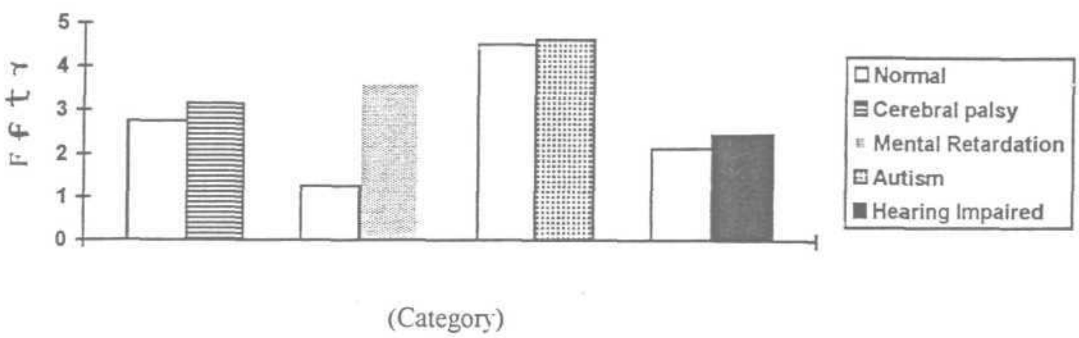
TABLE - VI(a) : Mean and SD values of Fo tremor frequency (Fftr) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels |a|, |i| and |u|.

Category (M.F)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M)	1.31	0.00	1.96	(0.56)	(0.00)	(0.95)	-	-r	-
Cerebral (M) Palsy (M)	1.81	4.76	4.01	(0.70)	(0.46)	(0.65)			
Normal (M)	1.46	0.95	1.78	(0.73)	(0.29)	(0.17)	+	+	-
Mental Retardation (M)	8.53	10.08	0.00	(3.80)	(4.12)	(0.00)			
Normal (M)	1.30	0.80	3.63	(0.12)	(0.34)	(0.57)	-	-	-
Autism (M)	0.00	0.79	4.00	(0.00)	(0.51)	(2.12)			
Normal (F)	2.09	1.23	1.29	(0.58)	(0.67)	(0.93)	-	-	-
Autism (F)	2.99	0.00	1.29	(0.92)	(0.00)	(0.87)			
Normal (M)	0.98	0.65	0.79	(0.54)	(0.47)	(0.73)	-	-	+
Hearing Impaired (M)	1.31	0.67	0.84	(0.81)	(1.33)	(1.15)			

	Mean			S.D.			Significance		
Category (M.F)	a	i	u	a	i	u	a	i	u
Normal (F)	1.17	0.00	0.00	(0.67)	(0.00)	(0.00)	-	-	-
Hearing Impaired (F)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)			

TABLE - **VI(b)** : Mean and SD values of Fo Tremor Frequency (Fftr) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	S.D.	Significance
Normal (Ctrl)	2.75	(1.34)	-
Cerebral Palsy (Exp)	3.15	(1.83)	
Normal (Ctrl)	1.26	(0.76)	
Mental Retardation (Exp)	3.64	(1.23)	
Normal (Ctrl)	4.53	(0.95)	-
Autism (Exp)	4.65	(1.89)	
Normal (Ctrl)	2.15	(0.87)	-
Hearing Impaired (Exp)	2.46	(0.93)	
Total of Normal group	3.09	(1.57)	-
Total of Experimental Group	2.48	(1.23)	



Normal controls of respective abnormal populations

Graph - VI : Comparison of Normal vs Developmental Speech and Language disordered groups in terms of Fo Tremor Frequency.

It can be seen from the tables - VI (a) and VI(b) that the (Fftr) values for |i| and |u| were higher in the cerebral palsy group (all males) when compared to their normal controls, results tending towards significant difference for |a| ($P > 0.05 < 0.06$). Considering the cerebral palsy males and females as a group no significant differences were seen for vowels. Similar trend was observed in the mentally retarded males for |a| and |i| when compared to their normal control subjects results significant at $P < 0.05$ level. No significant group differences were seen on comparing the autistic group (males and females), hearing impaired group (males and females) separately and as a whole with their respective control groups. However, a trend for higher Fftr values were observed in this group.

Thus the null hypothesis stating that there is no significant difference in terms of Fo tremor frequency (Fftr) between the normal subjects and subjects of the developmental speech and language disordered groups of cerebral palsy, mental retardation, autism and hearing impairment is partially rejected.

The reason for higher means of Fftr observed above may be due to inability in the developmental speech and language disordered population (cerebral palsy and mental retardation) to maintain a constant pitch in phonation. Thus it was concluded that the Fo tremor frequency is a good parameter in differentiating between the disordered groups and normals.

7. **Amplitude Tremor Frequency (Fatr)**:

The mean and standard deviation values of (Fatr) in the normal subjects and subjects of the developmental speech and language disordered groups are given in TablesVII(a) and VII(b).

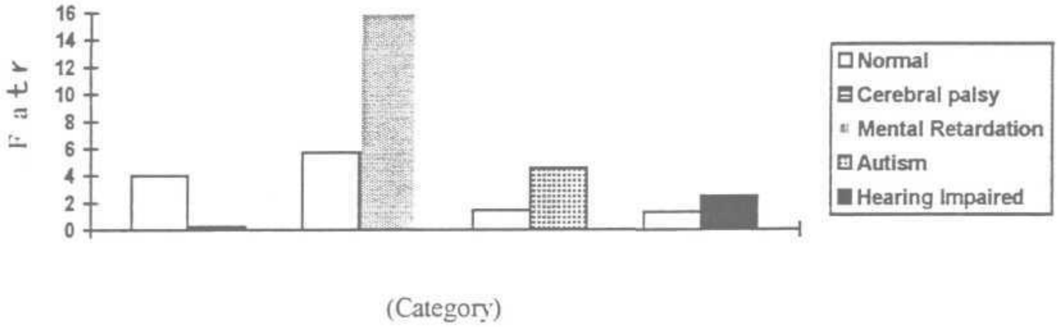
TABLE - VTJ(a): Mean and SD values of Amplitude Tremor Frequency (Fatr) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels |a|, |i| and |u|.

Category (M,F)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M)	3.15	3.65	4.44	(2.00)	(1.13)	(1.80)	+	+	+
Cerebral (M) Palsy (M)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)			

Category (M.F)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M)	2.18	3.41	2.26	(1.24)	(1.75)	(1.89)	-	+	-
Mental Retardation (M)	2.70	6.39	1.72	(2.40)	(2.50)	(1.60)			
Normal (M)	2.47	4.37	4.37	(1.23)	(1.86)	(1.86)	+	-	-
Autism (M)	9.22	3.21	3.23	(3.58)	(1.41)	(145)			
Normal (F)	1.85	1,80	1.87	(1.02)	(0.00)	(1.12)	-	-	-
Autism (F)	1.97	1.83	1.96	(0.23)	(0.98)	(1.30)			
Normal (M)	4.99	3.20	3.33	(4.66)	(2.45)	(1.66)	-	-	-
Hearing Impaired (M)	4.72	3.33	3.40	(1.80)	(0.66)	(1.62)			
Normal (F)	1.79	0.00	3.33	(0.85)	(0.00)	(0.66)	-	+	-
Hearing Impaired (F)	2.31	4.35	3.40	(1.26)	(1.14)	(1.32)			

TABLE - VTI(b) : Mean and SD values of Amplitude Tremor Frequency (Fatr) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	**S.D.**	Significance
Normal (Ctrl)	3.99	(1.78)	+
Cerebral Palsy (Exp)	0.23	(0.12)	
Normal (Ctrl)	5.71	(1.91)	+
Mental Retardation (Exp)	16.00	(5.21)	
Normal (Ctrl)	1.43	(0.51)	+
Autism (Exp)	4.55	(0.68)	
Normal (Ctrl)	1.32	(0.36)	-
Hearing Impaired (Exp)	2.04	(0.71)	
Total of Normal group	1.61	(0.73)	-
Total of Experimental Group	2.06	(1.87)	



Normal controls of respective abnormal populations

Graph - VII : Comparison of Normal vs Developmental Speech and Language disordered groups in Amplitude Tremor Frequency.

It can be seen from the tables - VII(a) and VII(b) that the cerebral palsy (males) showed lower values when compared to the normal control subjects for |a|, i| and ju|, results significant at P < 0.05 level. The same was observed on comparing cerebral palsy as a whole (males and females together) for vowels.

Comparing the normal controls and the mentally retarded (males) latter group showed significantly higher Fatr values for |i| at P < 0.05 level.

Comparing the normal and the autistic group, higher (Fatr) values were observed for |a| in males when compared to normal controls, results significant at P < 0.05 level. For |i| and |u| a trend for lower values were seen compared to normal controls. Autistic female subjects when compared with normal controls showed no significant group differences. Considering autistic group as a whole (males and females together) significant group differences at P < 0.05 level for vowels, were seen.

Comparing the normals and hearing impaired subjects, there were no significant group differences seen for male subjects for |a|, |i| and |u|. Female subjects showed higher Fatr value for |i| when compared to normal controls results tending towards significant difference (P > 0.05 < 0.06 level). Considering the hearing impaired group as a whole no significant differences were observed for vowels.

Thus the null hypothesis stating that there is no significant difference; in terms of Fatr between the normal subjects and subjects of developmental speech and language disordered group is partially rejected.

Considering results (lower Fatr values) obtained for cerebral palsy males when compared to normals could be attributed to inability of the cerebral palsy group to use their vocal system efficiently as compared to normals. Considering the results obtained for mentally retarded and autistic group (Fatr values being higher) than normal values for |a| and |i|, hearing impaired females (higher Fan-values for iii) when compared to normal controls could be due to inability to maintain a constant pitch and intensity as normals due lack of maturation of the vocal system.

Higher than normal values obtained in autistic (males) for |a| compared to normal control subjects could be attributed inability to use their vocal apparatus as efficiently as their normal controls, due to inadequate maturation of the vocal system.

Findings in the autistic population is in support of Goldfarb et. al., 1956; Pronovost et. al., 1966. who have noted loudness levels to fluctuate reflected by whispering, muttering and occasional ejaculations. This study supports that autistics have difficulty in maintaining constant pitch and intensity. This could also be viewed as a broader inability to perceive and interpret sound and contextual cues or a plain personal whim. The results give conclusive support that amplitude tremor frequency could differentiate the developmental speech and language disordered groups from normals.

8. Absolute Jitter (Jita):

The mean and standard deviation values of Jita in the normal subjects and subjects of the developmental speech and language disordered group have been given in Tables VIII (a) and VIII(b).

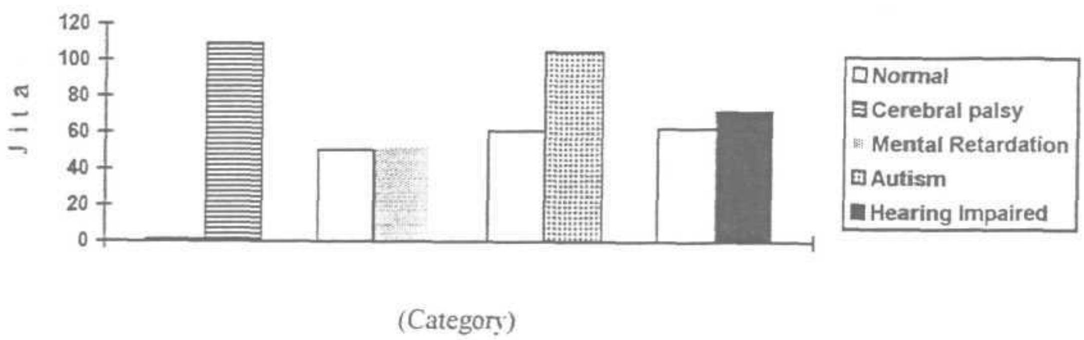
TABLE - VIII(a) : Mean and SD values of Absolute Jitter (Jita) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels |a|, |**i**| and |u|.

Category (M.F)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M) Cerebral (M) Palsy (M)	51.60 60.00	75.47 84.61	50.11 112.07	(20.96) (19.72)	(12.63) (40.96)	(22.61) (43.11)	-	-	+
Normal (M) Mental Retardation (M)	43.18 37.50	73.83 67.55	40.35 45.98	(22.40) (6.17)	(11.06) (13.32)	(16.81) (14.54)	-	-	-
Normal (M) Autism (M)	74.67 81.71	61.54 97.07	61.54 111.33	(41.63) (3916)	(44.17) (31.32)	(44.97) (60.86)	-	+	+
Normal (F) Autism (F)	33.27 113.58	34.10 97.54	67.86 187.86	(2.30) (17.11)	(3.21) (29.80)	(3.21) (49.21)	+	+	+
Normal (M) Hearing Impaired (M)	58.62 54.06	61.75 58.65	51.66 45.76	(20.61) (20.13)	(27.30) (19.11)	(7.05) (11.71)	-	-	-
Normal (F) Hearing Impaired (F)	33.14 36.62	39.39 42.52	31.65 45.76	(2.48) (10.89)	(3.92) (9.51)	(17.05) (7.14)	-	-	-

TABLE - Vm(b) : Mean and SD values of Absolute Jitter (Jita) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	S.D.	Significance
Normal (Ctrl) Cerebral Palsy (Exp)	1.19 109.19	(0.70) **(31.1)**	+

Category	Mean	S.D.	Significance
Normal (Ctrl)	50.46	(21.47)	-
Mental Retardation (Exp)	52.68	(17.05)	
Normal (Ctrl)	60.87	(20.45)	+
Autism (Exp)	104.36	(50.21)	
Normal (Ctrl)	62.49	(20.19)	-
Hearing unpaired (Exp)	71.68	(32.22)	
Total of Normal group	64.51	(20.47)	+
Total of Experimental Group	84.71	(34.32)	



Normal controls of respective abnormal populations

Graph - VIII : Comparison of Normal vs Developmental Speech and Language disordered groups in terms of Absolute Jitter.

It can be seen from the tables - VIII(a) and VIII(b) that Jita value for |u| was higher in the cerebral palsy (all males) group when compared to normal controls, results significant $P < 0.05$ level. Slightly higher than normal values were observed for |a| and |i|. Comparing the cerebral palsy as a group with normals, significant differences at $P < 0.05$ level were seen for vowels.

Comparing the normal and mentally retarded population **(all** males), no significant group differences were seen. Comparing the normal controls and autistic group (males and females), higher absolute values were seen in autistic group when compared to normal controls, results significant at $P < 0.05$ level for |i| and |u| in the autistic males and for |a|, |i| and |u| in the autistic females compared to their normal controls ($P < 0.05$ level). Comparing the autistics (both males and females) as a whole significantly higher Jitta was observed for vowels when compared to normals.

Comparing the normals and hearing impaired group, no significant group differences were observed in both males and females for vowels |a|, |i| and |u|. Same was seen when considering the group as a whole. Thus the null hypothesis stating that there is no significant differences in terms of absolute Jitter (Jita) between normal and subjects of the developmental speech and language disordered groups has been partially rejected.

Considering the findings in the developmental disordered populations of cerebral palsy and autism as described above when compared to their normal controls, could be due to inefficient control over the vocal system. This could be attributed to the variations in the vibratory patterns accompanied by transient pressure changes across the glottis (Von Leden et. al 1960) and due to limitations of the laryngeal neuro mechanism through the articular mucosal reflex system (Gould and Okamura, 1974), all indicating a lack of neuromotor maturation. It was conluded that absolute jitter is a useful parameter in differentiating between disordered groups and normals.

9. Jitter Percentage (Jitt) :

The mean and standard deviation values of Jitt in the normal subjects and subjects of the developmentally disordered group have been given in Tables - EX(a) and DC (b).

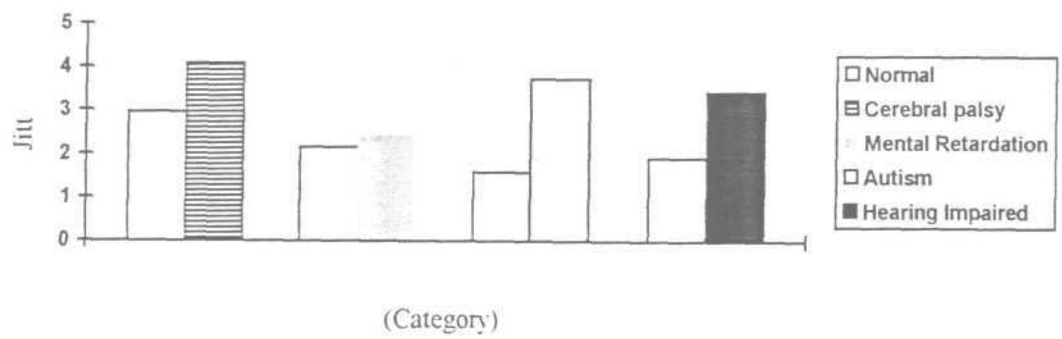
TABLE - IX(a) : Mean and SD values of Jitter percentage (jitt) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels |a|, |i| and |u|.

Category (M,F)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M)	1.90	2.77	4.42	(1.39)	(0.69)	(2.98)	-	-	-
Cerebral (M) Palsv(M)	1.60	2.79	4.50	(0.57)	(1.30)	(2.96)			
Normal (M)	0.85	1.79	0.99	(0.30)	(0.47)	(0.53)	-	-	-
Mental Retardation (M)	1.08	2.07	1.60	(0.20)	(0.40)	(0.50)			
Normal (M)	1.67	1.28	1.28	(1.27)	(0.53)	(0.53)	-	-	-
Autism (M)	2.52	2.04	3.13	(149)	(1.26)	(2.12)			
Normal (F)	1.00	0.97	3.93	(0.12)	(0.18)	(1.87)	-	-	-
Autism (F)	2.75	2.34	3.94	(1.53)	(1-27)	(1.96)			
Normal (M)	1.69	1.50	1.77	(0.79)	(0.71)	(1.13)	-	-	-
Hearing Impaired (M)	1.47	1.83	1.62	(0.78)	(0.66)	(0.23)			
Normal (F)	1.05	1.31	1.77	(0.49)	(0.50)	(0.27)	-	-	-
Hearing Impaired (F)	1.32	1.76	1.62	(0.69)	(0.29)	(0.23)			

TABLE - IX(b) : Mean and SD values of Jitter percentage (jitt) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	S.D.	Significance
Normal (Ctrl)	2.96	(1.59)	+
Cerebral Palsy (Exp)	4-08	(31.75)	
Normal (Ctrl)	2.14	(0.58)	-
Mental Retardation (Exp)	2.46	(0.54)	
Normal (Ctrl)	1.57	(0.97)	+
Autism (Exp)	*3.71*	(1.03)	

Category	Mean	**S.D.**	Significance
Normal (Ctrl)	1.91	(0.39)	
Hearing Impaired (Exp)	5.41	(2.37)	
Total of Normal group	1.74	(1.25)	
Total of Experimental Group	2.39	**(1.16)**	



Normal controls of respective abnormal populations

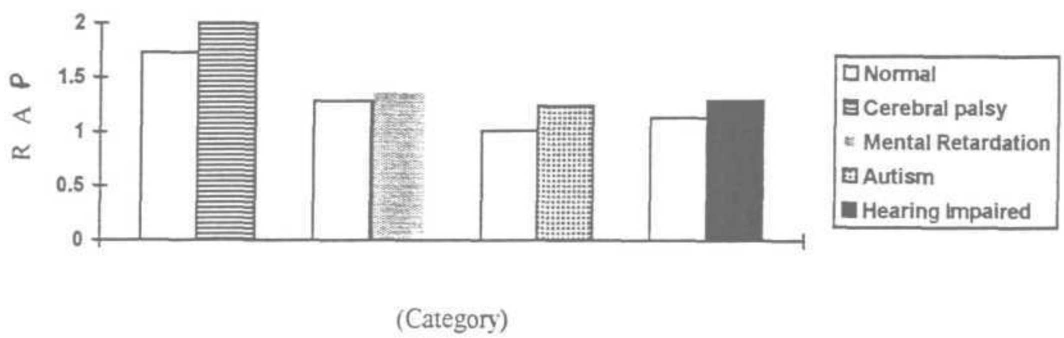
Graph - IX : Comparison of Normal vs Developmental Speech and Language disordered groups in terms of Jitter percentage.

It can be seen from the tables - IX(a) and IXfb) that were no significant group difference for Jitt values for ja|, |i| and |u| in the developmental speech and language disordered groups of cerebral palsy, mental retardation, autism, hearing impaired when compared to their normal control groups.

However, tendency for higher Jitt value were obsen'ed in mentally retarded (all males) and autistics (males and females) for |a|, i and |u| when compared to their normal control groups. When all the disordered groups were considered as a whole, all groups except mentally retarded showed significantly higher jitter percentage values (at $P < 0.05$ level) for vowels when compared to normal controls.

TABLE - X(b) : Mean and SD values of Relative Average Perturbation Quotient (RAP) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	S.D.	Significance
Normal (Ctrl) Cerebral Palsy (Exp)	1.73 2.00	(0.51) (0.64)	-
Normal (Ctrl) Mental Retardation (Exp)	1.28 1.37	(0.33) (0.33)	-
Normal (Ctrl) Autism (Exp)	1.01 1.24	(0.35) (0.52)	-
Normal (Ctrl) Hearing Impaired (Exp)	1.13 1.20	(0.32) (0.82)	-
Total of Normal group Total of Experimental Group	1.06 1.40	(0.95) (1.15)	-



Normal controls of respective abnormal populations

Graph - X : Comparison of Normal vs Developmental Speech and Language disordered groups in terms of Relative Average Perturbation Quotient.

It can be seen from the tables - X(a) and X(b) that there are no significant differences in RAP values for |**a**|, |i| and |u| in the developmental speech and language disordered group when compared to their normal control groups. Same was observed for vowels when each of the disordered groups were considered as a whole (both males and females together).

Thus the null hypothesis that there is no significant differences in terms of (Jitt) between the normals and the subjects of developmental speech and language disordered groups of cerebral palsy, mental retardation , autism, and hearing impairment is partially rejected.

The tendency for higher Jitt values in the mentally retarded and autistic population indicates that these clinical populations does not have an adequate control of the vocal sys tern and also an inability to maintain a constant pitch which has been also reflected by Jita findings. The hearing impaired population seems to have a better control over the vocal system compared to other groups considering males and females separately.

10. Relative average perturbation quotient (RAP) :

The mean and standard deviations values RAP in the normal and developmental spech and language disordered populations for ja|, |i| and |uj have been shown in Tables -X(a) and X(b).

TABLE - X(a) : Mean and SD values of Relative Average Perturbation Quotient (RAP) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels |a[, |i| and |u!.

Category- (MF)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M)	1.14	1.07	2.55	(0.81)	(0.37)	(0.87)	-	-	-
Cerebral (M) PalsyM)	0.95	1.58	2.02	(0.31)	(1.12)	(0.96)			
Normal (M)	0.58	1.06	0.58	(0.27)	(0.27)	(0.28)	-	-	-
Mental Retardation (M)	0.91	1.24	0.92	(0.31)	(0.24)	(0.01)			
Normal (M)	1.15	0.93	0.93	(0.88)	(0.31)	(0.46)	-	-	-
Autism (M)	1.56	1.23	1.84	(1.12)	(0.92)	(1.23)			
Normal (F)	0.61	0.59	2.06	(0.27)	(0.33)	(1.27)	-	-	-
Autism (F)	1.64	1.39	2.06	(0.53)	(0-31)	(0.37)			
Normal (M)	1.02	0.91	2.02	(0.74)	(0.42)	(1.13)	-	-	-
Hearing Impaired (M)	0.89	1.09	0.98	(0.43)	(0.39)	(0.16)			
Normal (F)	0.79	0.64	0.97	(0.41)	(0.33)	(0.47)	-	-	-
Hearing Impaired (F)	0.81	0.79	0.93	(0.42)	(0-42)	(0.33)			

Thus the null hypothesis stating that there is no significant difference in terms of relative average perturbation quotient (RAP) between the normal subjects and the subjects of developmental speech and language disordered groups of cerebral palsy mental retardation, autism, hearing impairment and their normal control groups is accepted.

11. Pitch Period Perturbation Quotient (PPQ):

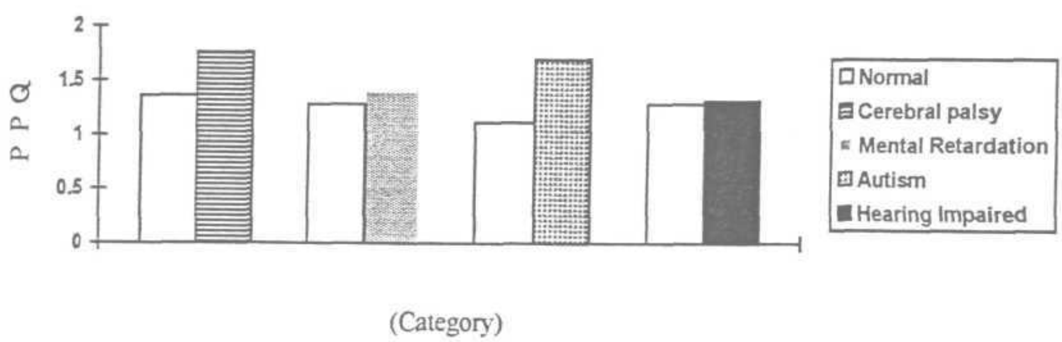
The mean and standard deviation values of PPQ in the normal and developmental speech and language disordered groups for |a! ii| and |u| have been shown in tables - XI(a) and XI(b).

TABLE - XI(a) : Mean and SD values of Pitch Period Perturbation Quotient (PPQ) in both normals and developmental speech and language disordered groups (males and or females) for the vowels |a|, |i| and ju|.

Category (M.F)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M)	1.10	1.46	3.10	(0.91)	(0.91)	(1.60)	-	-	-
Cerebral (M) PalsvfM)	0.97	1.66	2.00	(0.36)	(0.98)	(0.71)			
Normal (M)	0.47	1.08	0.63	(0.12)	(0.28)	(0.30)	-	-	-
Menial Retardation (M)	0.62	1.17	0.85	(0.11)	(0.22)	(0.27)			
Normal (M)	1.25	1.01	1.01	(0.71)	(0.61)	(0.61)	-	-	-
Autism (M)	1.56	1.17	1.84	(0.92)	(0.35)	(0.78)			
Normal (F)	0.59	0.58	2.73	(0.26)	(0.13)	(1.04)	-	-	-
Autism (F)	1.65	1.39	2.73	(0.24)	(0.39)	(0.92)			
Normal (M)	1.03	1.17	0.98	(0.78)	(0.90)	(0.26)	-	-	-
Hearing Impaired (M)	0.80	1.06	0.93	(0.24)	(0.43)	(0.36)			
Normal (F)	0.63	0.66	0.86	(0.23)	(0.27)	(0.34)	-	-	-
Hearing Impaired (F)	0.77	1.06	0.93	(0.31)	(0.59)	(0.37)			

TABLE - XI(b): Mean and SD values of Pitch Period Perturbation Quotient (PPQ)in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	S.D.	Significance
Normal (Ctrl)	1.36	(0.59)	-
Cerebral Palsy (Exp)	1.76	(0.87)	
Normal (Ctrl)	1.28	(0.36)	-
Mental Retardation (Exp)	1.40	(0.30)	
Normal (Ctrl)	1.11	(0.67)	-
Autism (Exp)	1.69	(0.81)	
Normal (Ctrl)	1.28	(0.51)	-
Hearing Impaired (Exp)	1.31	(0.47)	
Total of Normal group	1.17	(0-31)	-
Total of Experimental Group	1.43	(0.65)	



Normal controls of respective abnormal populations

Graph - XI : Comparison of Normal vs Developmental Speech and Language disordered groups in terms of Pitch Period Perturbation Quotient.

It can be seen from the tables - XI(a) and XI(b) that there are no significant differences in PPQ values for |a|, |i| and |u| in the developmental speech and language disordered groups when compared to their normal control groups.

Thus the null hypothesis stating that there is no significant difference in terms of pitch period perturbation quotient (PPQ) between the subjects normal and subjects of developmental speech and language disordered groups of cerebral palsy, mental retardation, autism, hearing impairment was accepted.

12. Smoothed Pitch Period Perturbation (SPPQ) :

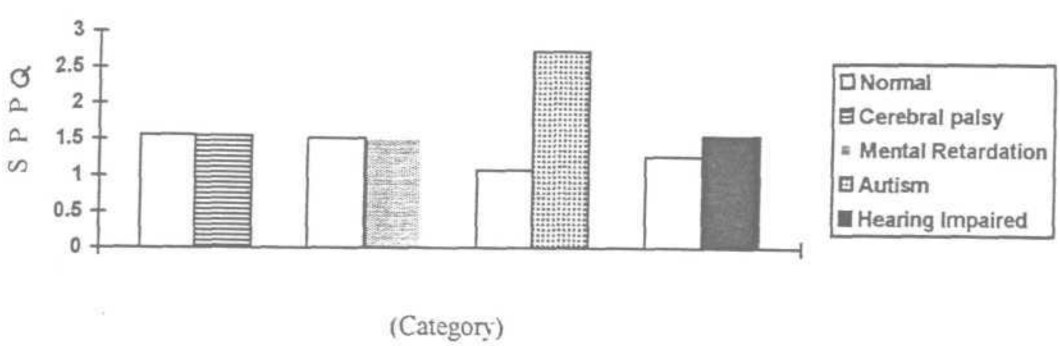
The mean and standard deviation values of SPPQ values for |a|, |i| and |u| in both normal and developmental spech and language disordered groups of cerebral palsy, mental retardation, autism and hearing impairment have been shown in tables -XII(a) and XII(b).

TABLE - XII(a) : Mean and SD values of in Smoothed Pitch Period Perturbation (SPPQ) both normals and developmental speech and language disordered groups (males and/or females) for the vowels ja|, |i| and |u'.

Category (M.F)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M)	1.38	1.21	2.91	(0.62)	(0.31)	(0.59)	-	-	-
Cerebral (M) Palsy (M)	1.16	1.26	1.48	(0.38)	(0.56)	(0.30)			
Normal (M)	0.68	1.15	0.74	(0.19)	(0.48)	(0.33)	-	-	-
Mental Retardation (M)	0.70	1.15	0.88	(0.31)	(0.44)	(0.28)			
Normal (M)	1.26	0.96	1.00	(0.66)	(0.34)	(0.59)	+	-	-
Autism (M)	5.49	1.43	1.82	(2.48)	(0.48)	(0.56)			
Normal (F)	0.65	0.68	2.62	(0.28)	(0.27)	(1.31)	+	-	-
Autism (F)	4.12	1.71	3.06	(1.42)	(0.41)	(1.62)			
Normal (M)	1.19	0.98	2.53	(0.74)	(0.47)	(1.14)	-	-	-
Hearing Impaired (M)	1.39	1.23	1.01	(0.64)	(0.51)	(0.36)			
Normal (F)	0.70	0.82	2.42	(0.11)	(0.07)	(0.94)	-	-	-
Hearing Impaired (F)	0.91	1.16	1.01	(0.48)	(0.36)	(0.29)			

TABLE - XII(b): Mean and SD values of Smoothed Pitch Period Perturbation (SPPQ) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	**S.D.**	Significance
Normal (Ctrl)	1.56	(0.57)	-
Cerebral Palsy (Exp)	1.55	(0.59)	
Normal (Ctrl)	1.51	(0.31)	-
Mental Retardation (Exp)	1.51	(0.28)	
Normal (Ctrl)	1.07	(0.52)	
Autism (Exp)	2.71	(0.97)	
Normal (Ctrl)	1.26	(1.01)	-
Hearing Impaired (Exp)	1.54	(0.81)	
Total of Normal group	1.18	(0.71)	+
Total of Experimental Group	1.78	(0.55)	



☐ Normal controls of respective abnormal populations

Graph - XII : Comparison of Normal vs Developmental Speech and Language disordered groups in terms of Smoothed Pitch Period Perturbation.

Comparing the cerebral palsy, mentally retarded and hearing impaired with their respective normal control groups, no significant group differences were seen for SPPQ measures for |a|. |i| and |u|. Same was seen for vowels when each of disordered population were considered as a whole (both males and females together) and compared to normals.

Comparing the normals and autistic group (males and females), higher SPPQ values were seen for a|. Significantly higher than normal SPPQ values **were** seen for vowels (P < 0.05 level), when autistic group (both males and femaks together) were compared with normals.

Thus the null hypothesis stating that there is no significant differences m terms of smoothed pitch period perturbation quotient between the normal subjects and subjects of the developmental spech and language disordered groups of cerebral palsy, mental retardation, autism hearing impairment is partially rejected.

Considering the findings in the autistic group both males and females separately and together as a group compared to normals could be attributed to the inability of this group to maintain a constant pitch during phonation.

Goldfarb et.al.. 19575; 1972; Simon 1975, have found tendency **for** excessively high pitch levels. Insufficient pitch changes have also been noted by some of these authors.

13. Frequency Tremor Intensity **Index (FTRI)**:

The mean and standard deviation values of FTRI for |a|, |i| and |u| in normals and the developmental speech and language disordered groups of cerebral palsy mental retardation autism and hearing impairment have been shown in Tables - XIII(a) and XIII(b).

TABLE - XIII(a) : Mean and SD values of Frequency tremor intensity index (FTRI) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels |a|, |i| and **|u|.**

Category (MF)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M) Cerebral Palsy (M)	0.71 0.66	0.67 0.35	0.83 0.18	(0.13) (0.11)	(0.23) (0.17)	(0.19) (0.01)	-	-	-
Normal (M) Mental Retardation (M)	0.27 0.20	0.15 0.63	0.30 0.13	(0.16) (0.03)	(0.01) (0.29)	(0.02) (0.01)	-	-	-
Normal (M) Autism (M)	0.38 0.23	0.45 0.15	0.45 0.34	(0.05) (0.03)	(0.12) (0.02)	(0.16) (0.12)	-	-	-
Normal (F) Autism (F)	0.84 0.18	0.25 0.34	0.62 0.52	(0.37) (0.07)	(0.18) (0.12)	(0.25) (0.15)	-	-	-
Normal (M) Hearing Impaired (M)	0.50 0.93	0.34 0.23	0.74 0.81	(0.14) (0.34)	(0.13) (0.12)	(0.23) (0.21)	-	-	-
Normal (F) Hearing Impaired (F)	0.96 -	0.87 -	0.70 -	(0.42 -	(0.35) -	(0.31) -	-	-	-

TABLE - XIII(b) : Mean and SD values of Frequency tremor intensity index (FTRI) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	**S.D.**	Significance
Normal (Ctrl) Cerebral Palsy (Exp)	0.39 0.63	(0.17) (0.77)	-
Normal (Ctrl) Mental Retardation (Exp)	0.77 0.96	(0.28) (0.33)	-
Normal (Ctrl) Autism (Exp)	0.40 0.30	(0.12) (0.07)	-

Category	Mean	S.D.	Significance
Normal (Ctrl)	0.47	(0.23)	-
Hearing Impaired (Exp)	0.43	(0.28)	
Total of Normal group	0.41	(0.17)	-
Total of Experimental Group	0.35	(0.23)	

It can be seen from the tables - XIII(a) and XIII(b) that are no significant group differences for FTRI values for |a|, |i| and |u| betwen normals and developmental speech and language disordered groups. Same was observed for vowels when each of the disordered groups (both males and females together) were compared to their normal control groups.

Thus the null hypothesis stating that there is no significant difference terms of frequency tremor intensity index (FTRI) between the normal subjects and subjects of developmental speech and language disordered groups of cerebral palsy, mental retardation, autism hearing impairment is accepted.

14. Fundamental Frequency Variation (vFO):

The mean and standard deviation values of vFO for |a|, |i| and ju| for the normals and developmental speech and language disordered groups of cerebral palsy, mental retardation, autism and hearing impairment has been shown in Tables - XIV(a) and XIV(b).

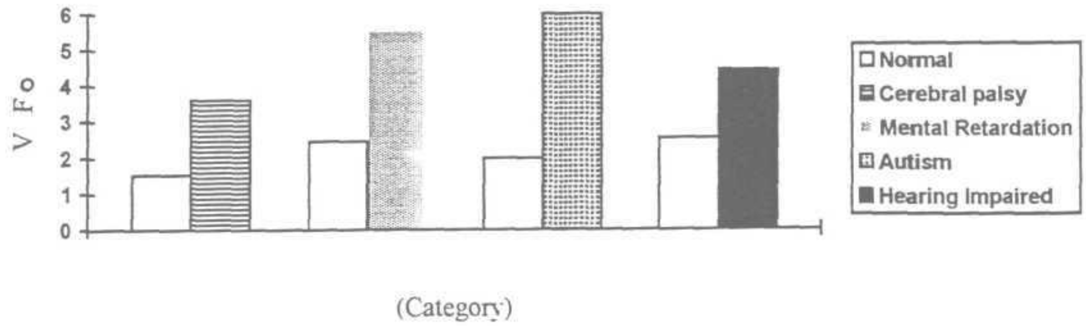
TABLE - **XIV** (a) : Mean and SD values of Fundamental Frequency variation (vFO) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels |a', |i| and |u|.

Category (MJ[7])	Mean			SD.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M)	2.20	2.24	2.27	(103)	(0.81)	(0.98)	-	+	+
Cerebral (M) Palsv (M)	2.70	4.14	4.14	(1.06)	(2.30)	(2.18)			

Category (M,F)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M)	1.28	2.12	1.20	(0.43)	(0.55)	(0.48)	-	+	-
Mental Retardation (M)	2.36	3.04	2.04	(0.88)	(1.69)	(0.70)			
Normal (M)	2.18	1.60	1.70	(0.92)	(0.58)	(0.48)	+	-	
Autism (M)	12.59	3.26	6.26	(8.44)	(1.97)	(3.95)			
Normal (F)	1.84	1.04	4.77	(0.94)	(0.25)	(1.62)	-	+	-
Autism (F)	3.35	3.38	4.77	(1.26)	(1.15)	(2.61)			
Normal (M)	2.04	1.86	4.53	(0.97)	(0.93)	(1.85)	-	+	-
Hearing Impaired (M)	3.21	4.09	3.28	(1.61)	(1.76)	(1.32)			
Normal (F)	1.95	1.66	4.43	(0.79)	(0.86)	(2.48)	+	+	-
Hearing Impaired (F)	6.08	6.25	3.28	(2.76)	(2.41)	(2.32)			

TABLE - XTV(b): Mean and SD values of Fundamental Frequency variation (vFO) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	S.D.	Significance
Normal (Ctrl)	1.53	(0.37)	+
Cerebral Palsy (Exp)	3.61	(1.98)	
Normal (Ctrl)	2.44	(0.54)	+
Mental Retardation (Exp)	5.53	(1.15)	
Normal (Ctrl)	1.98	(0.45)	
Autism (Exp)	5.97	(1.89)	
Normal (Ctrl)	2.53	(0.96)	+
Hearing Impaired (Exp)	4.41	(2.27)	
Total of Normal group	2.21	(2.24)	+
Total of Experimental Group	4.37	(1.91)	



Normal controls of respective abnormal populations

Graph - XIII : Comparison of Normal vs Developmental Speech and Language disordered groups in terms of Fundamental Frequency variation.

It can be seen from the tables - XIV(a) and XIV(b) that cerebral palsy group (all males) showed higher (vFo) values for |a|, ii| and |u| when compared to normal controls, results significant at P < 0.05 level.

Comparing the normal and mentally retarded group, no significant differences were seen in vFo for |a|, |i| and |u| however, a tendency for slightly higher values were seen in the mentally retarded (all males) compared to their normal control subjects. However, considering the mentally regarded group as a whole, significantly higher values were seen for vowels at P < 0.05 level when compared to normal controls. Comparing the normal and autistic group, higher vFo values for |a|, |i| and |u| were observed in the autistic group (males) when compared to their normals control groups, results significant at P < 0.05 level.

In female subjects, vFo values for |a| and |i| were higher when compared to normal controls, results tending towards significant diffirence (P > 0.05 < 0.06) for |i|. Comparing the autistic group as a whole (both males and females together), significantly higher vFo values were seen for vowels at P < 0.05 level when compared to normals.

Comparing the normal and hearing impaired group higher vFo values for |i| was seen in the hearing impaired (males) when compared to normal control group results tending towards significant difference (P > 0.05 < 0.06 level).

Tendency for higher vFo value in |a| was also observed in the hearing impaired female subjects although results were not significant. Comparing the hearing impaired females with their normal controls higher than normal vFo values were seen for |a| and |l|, results significant at P < 0.05 level. Considering the hearing impaired as a whole (both males and females together), significantly higher vFo not values at P < 0.05 level, were observed for vowels.

Thus the null hypothesis stating that there is no significant difference in terms of fundamental frequency (vFo) between normal subjects and the subjects of the developmental speech and language disordered groups of cerebral palsy, mental retardation, autism, hearing impairment was partially rejected.

The high (vFo) values seen in the developmental speech and language disordered groups of cerebral palsy, mental retardation, autism and hearing impairment when compared to their normal controls may be attributed to their inability to maintain the constant pitch during phonation. Kent (1976) has stated that standard deviations for the Fo measurements progressively decreased with age until (10 - 12) years of age. Thus it can be seen that with age the variability of Fo decreases ie., with matulation of the vocal system, refinement of control begins to occur. The finding in the developmental disordered populations could be attributed to delayed neuro-motor maturation of the vocal tract.

It was concluded that fundamental frequency variation could differentiate the developmental disordered speech and language groups from normals.

15. Shimmer in dB (ShdB):

The mean and SD values of ShdB for |a|, |i| and |u[in normals and the developmental disordered groups are presented in Tables XV(a) and XV(b).

TABLE - XV(a): Mean and SD values of Shimmer in dB (ShdB) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels |a|, |i| and |u|.

Category (M.F)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M) Cerebral (M) Palsy (M)	0.10 0.09	0.04 0.14	0.48 0.35	(0.04) (0.04)	(0.01) (0.01)	(0.14) (0.05)	-	-	-
Normal (M) Mental Retardation *(M)*	0.07 0.05	0.11 0.10	0.14 0.06	(0.01) (0.01)	(0.02) (0.06)	(0.04) (0.03)	-	-	-
Normal (M) Autism (M)	0.11 0.11	0.06 0.07	0.06 0.15	(0.05) (0.05)	(0.02) (0.02)	(0.01) (0.06)	-	-	-
Normal (F) Autism (F)	0.08 0.07	0.04 0.07	0.97 0.96	(0.02) (0.01)	(0.01) (0.01)	(0.21) (0.24)	-	-	-
Normal (M) Hearing Impaired (M)	0.09 0.11	0.05 O.OS	0.37 0.07	(0.01) (0.05)	(0.02) (0.02)	(0.11) (0.01)	-	-	-
Normal (F) Hearing Impaired (F)	0.09 0.09	0.04 0.05	0.11 0.07	(0.02) (0.01)	(0.01) (0.02)	(0.01) (0.01)	-	-	-

TABLE - XV(b) : Mean and SD values of Shimmer in dB (ShdB)in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	S.D.	Significance
Normal (Ctrl) Cerebral Palsy (Exp)	0.25 0.43	(0.11) (0.12)	-
Normal (Ctrl) Mental Retardation (Exp)	1.54 1.07	(0.54) (0.04)	-
Normal (Ctrl) Autism (Exp)	0.12 0.20	(0.07) (0.12)	-

Category	Mean	**S.D.**	Significance
Normal (Ctrl)	0.14	(0.12)	-
Hearing Impaired (Exp)	0.12	(0.01)	
Total of Normal group	0.13	(0.02)	
Total of Experimental Group	0.16	(0.12)	

It can be seen from the table that there were no significant group diffences in terms ShdB in the normals and subjects developmentally disordered groups.

Thus the null hypothesis stating there is no significant difference in terms of Shimmer in dB (ShdB) between the subjects of developmentally disordered groups and their normal control groups was accepted.

16. Shimmer in Percent (Shim):

The mean and SD values of Shim for |a|, ii| and |u| in the normals and developmental disordered groups are presented in tables - XVI(a) and XVI(b).

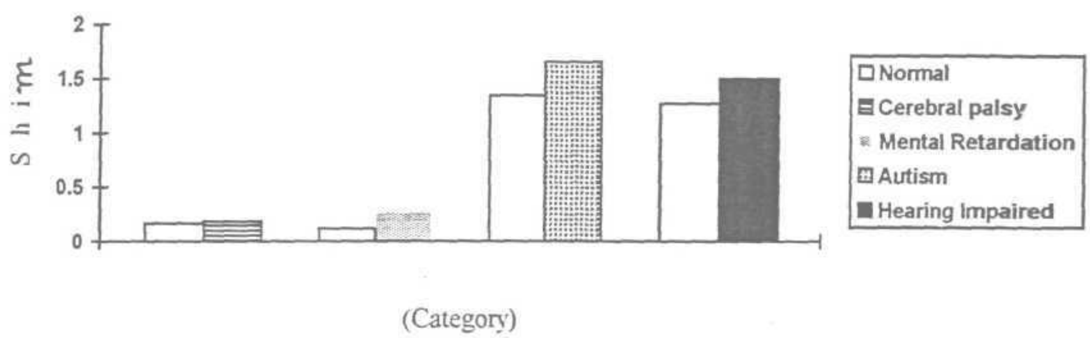
TABLE - XVI (a): Mean and SD values of Shimmer in Percent (Shim) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels |a|, jil and |u|.

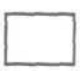
Category- (MF)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M) Cerebral (M) Palsy (M)	0.19 0.25	0.56 0.91	0.89 0.95	(0.12) (0.15)	(0.01) (0.50)	(0.16) (0.43)	-	-	-
Normal (M) Mental Retardation (M)	0.84 0.65	1.23 1.12	0.65 0.61	(0.03) (0.08)	(0.51) (0.36)	(0.14) (0.27)	-	-	-
Normal (M) Autism (M)	1.36 1.29	0.73 0.95	0.73 1.55	(0.60) (0.56)	(0.12) (0.05)	(0.04) (0.64)	-	-	-
Normal (F) Autism (F)	0.90 0.84	0.45 0.83	0.57 0.80	(0.29) (0.08)	(0.18) (0.09)	(0.15) (0.07)	-	-	-
Normal (M) Hearing Impaired (M)	1.09 1.33	0.68 0.78	0.76 0.83	(0.41) (0.65)	(0.12) (0.12)	(0.14) (0.41)	-	-	-

Category (MLF)	Mean			S.D.			Significance		
	a	1	u	a	i	u	a	i	u
Normal (F)	1.03	0.50	0.76	(0.13)	(0.03)	(0.13)	-	-	-
Hearing Impaired (F)	0.96	0.63	0.83	*(0.06)*	(0.07)	(0.13)			

TABLE - XVI(b): Mean and SD values of Shimmer in Percent (Shim) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	**S.D.**	Significance
Normal (Ctrl)	0.17	(0.02)	-
Cerebral Palsy (Exp)	1.19	(1.05)	
Normal (Ctrl)	0.12	(0.08)	-
Mental Retardation (Exp)	0.20	(0.06)	
Normal (Ctrl)	1.34	(0.82)	-
Autism (Exp)	1.65	(0.72)	
Normal (Ctrl)	1.26	(0.56)	-
Hearing Impaired (Exp)	1.49	(0.97)	
Total of Normal group	1.44	(1.15)	-
Total of Experimental Group	1.52	(1.25)	



 Normal controls of respective abnormal populations

Graph - XIV : Comparison of Normal vs Developmental Speech and Language disordered groups in terms of Shimmer in Percent.

It can be seen from the tables - XVI(a) and XVI(b) that there were no significant group differences in terms of Shim in the normals and subjects of the developmental speech and language disordered groups.

Thus the null hypothesis stating there is no significant difference in terms of shimmer percent (Shim) between the normal subjects and subjects of developmental speech and language disordered groups was accepted.

17. Amplitude Perturbation Quotient (AP Q) :

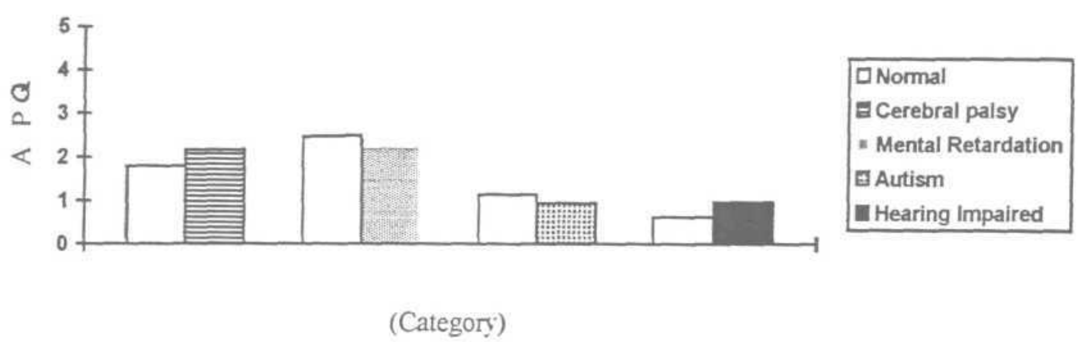
The mean and SD values of APQ for [aj |ij and |u| in normals and the developmental speech and language disordered groups have been shown in tables - XVII(a) and XVII(b).

TABLE - XVII(a) : Mean and SD values of Amplitude perturbation quotient (APQ) in both normals and developmental speech and language disordered groups (males and /or females) for the vowels |a|, |i| and |u|.

Category (M.F)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M)	0.83	0.39	1.22	(0.34)	(0.07)	(0.89)	-	-	
Cerebral (M) Palsv(M)	0.70	0.68	3.58	(0.27)	(0-14)	(1.06)			
Normal (M)	0.57	0.94	1.29	(0.02)	(0.51)	(0.32)	-	-	-
Mental Retardation (M)	0.44	0.87	0.99	(0.06)	(0.27)	(0.29)			
Normal (M)	0.93	0.51	0.50	(0.39)	(0.29)	(0.21)	-	-	-
Autism (M)	0.94	1.03	1.48	(0.37)	(0.86)	(0.85)			
Normal (F)	0.41	0.32	0.51	(0.26)	(0.03)	(0.06)	-	-	-
Autism (F)	0.50	0.52	0.51	(0.05)	(0.09)	(0.07)			
Normal (M)	0.76	0.39	1.16	(0.31)	(0.11)	(0.72)	-	-	-
Hearing Impaired (M)	0.97	0.58	0.71	(0.54)	(0.14)	(0.47)			
Normal (F)	0.45	0.33	0.67	(0.16)	(0.02)	(0.22)	-	-	-
Hearing Impaired (F)	0.69	0.41	0.71	(0.16)	(0.06)	(0.12)			

TABLE - XVII(b) : Mean and SD values of Amplitude perturbation quotient (APQ) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	**S.D.**	Significance
Normal (Ctrl)	1.78	(0.56)	-
Cerebral Palsy (Exp)	2.16	(0.99)	
Normal (Ctrl)	2.28	(1.06)	
Mental Retardation (Exp)	2.24	(0.76)	
Normal (Ctrl)	1.13	(0.35)	-
Autism (Exp)	0.94	(0.31)	
Normal (Ctrl)	0.62	(0.53)	—
Hearing Impaired (Exp)	0.97	(0.29)	
Total of Normal group	1.32	(0.52)	-
Total of Experimental Group	1.16	(0.98)	



Normal controls of respective abnormal populations

Graph - XV : Comparison of Normal vs Developmental Speech and Language disordered groups in terms of Amplitude perturbation quotient..

It can be seen from the table that there were no significant group differences for |a| and |i| in cerebral palsy group (all males) when compared to their normal controls. Significantly group differences (higher APQ) were seen for |u| at P < 0.05 level.

Thus the null hypothesis stating that there were no significant differences between normals and subjects of the developmental speech and language disorders is partially rejected.

APQ measures the short term (cycle to cycle with smoothing factor of 11 periods irregularity of the peak-to-peak amplitude of the voice. It is less sensitive to the period to period amplitude variations yet still describes the short term amplitude perturbation of the voice . Increased APQ values seen in cerebral palsy group is consistent with the breathy and hoarse components in the voice of this developmental disordered population and also could be attributed to the inability to maintain constant intensity. Thus it was concluded that Amplitude perturbation quotient could differentiate between normals and developmental speech and language disordered groups.

18. Smoothed Amplitude Perturbation Quotient (SAPQ):

The mean and SD values of SAPQ fr |a|, |i| and |u| in the normals and developmental speech and language disordered groups are given in tables - XVIII(a)and XVIII(b).

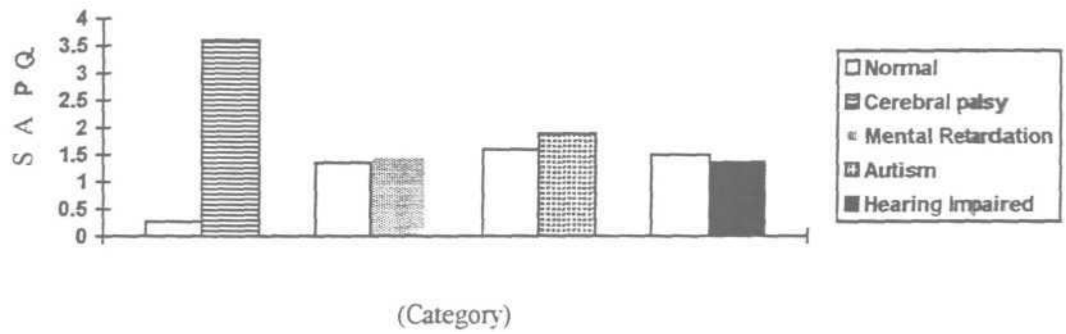
TABLE - XVin(a) : Mean and SD values of Smoothed Amplitude Perturbation Quotient (SAPQ) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels |a|, |i| and |u|.

Category (MF)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M)	0.86	0.47	0.98	(0.31)	(0.91)	(0.30)	-	-	+
Cerebral Palsy (M)	0.72	1.23	6.75	(0.25)	(1.27)	(2.55)			
Normal (M)	0.63	1.23	2.55	(0.02)	(0.78)	(0.42)	-	-	-
Mental Retardation (M)	0.52	1.06	2.48	(0.12)	(0.99)	(0.84)			
Normal (M)	0.95	0.62	0.62	(0.38)	(0.33)	(0.33)	-	-	+
Autism (M)	1.08	1.74	4.26	(0.33)	(0.45)	(1.44)			
Normal (F)	0.76	0.34	0.50	(0.19)	(0.03)	(0.16)	-	-	-
Autism (F)	0.83	0.82	0.50	(0.21)	(0.22)	(0.16)			

Category (M,F)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	I	u
Normal (M)	0.79	0.52	0.74	(0.28)	1 (0.25)	(0.44)	-	-	+
Hearing Impaired (M)	1.18	0.58	7.60	(0.56)	(0.13)	(2.69)			
Normal (F)	0.80	0.55	0.74	(0.13)	(0.13)	(0.44)	-	-	+
Hearing Impaired (F)	0.76	0.43	7.60	(0.28)	(0.08)	(2.70)			

TABLE - XVIII(b) : Mean and SD values of Smoothed Amplitude Perturbation Quotient (SAPQ) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	S.D.	Significance
Normal (Ctrl)	0.26	(1.05)	+
Cerebral Palsy (Exp)	3.61	(1.80)	
Normal (Ctrl)	1.35	(0.79)	-
Mental Retardation (Exp)	1.47	(0.47)	
Normal (Ctrl)	1.59	(0.57)	-
Autism (Exp)	1.89	(0.79)	
Normal (Ctrl)	1.50	(1.12)	-
Hearing Impaired (Exp)	1.37	(0-65)	
Total of Normal group	1.18	0.51	—
Total of Experimental Group	138	1.21	



Normal controls of respective abnormal populations

Graph - XVI : Comparison of Normal vs Developmental Speech and Language disordered groups in terms of Smoothed Amplitude Perturbation Quotient.

It can be seen from the tables - XVIII(a) and XVIII[(b) that there were no significant differences for |a| and |i| in the cerebral palsy group (all males) when compared to their normal controls, however significant group difference were seen for |u|. APQ value being higher in the cerebral palsy group when compared to normal control, group $P < 0.05$ level. Considering the cerebral palsy as a group (both males and females together), higher SAPQ values were seen for vowels, results significant at $P < 0.05$ level.

No significant group differences were seen between the mentally retarded and their normal controls. Comparing the autistic group with their normal controls, autistic males, showed greater SAPQ values for |u|, results tending towards significant difference ($P > 0.05 < 0.06$ level). There were no significant group differences between the autistic female and their normal control group for |a|, |i| and |u|.

Comparing the normal and hearing impaired group, there were no significant differences for in SAPQ |a| and |i|, but higher SAPQ values were seen for |uj in both males and females when compared to their normal controls, results significant at $P < 0.05$ level. Comparing the disordered groups of mental retardation, autism and hearing impaired as a whole with their normal controls, no significant differences between groups were seen.

Thus the null hypothesis stating that there is no significant difference in terms of smoothed average perturbation quotient (SAPQ) between the normal subjects and subjects of developmental sppech and language disordered groups of cerebral palsy, mental retardation, autism, hearing impairment has been partially rejected.

The SAPQ smoothing factor set up in smoothing factor of 55 provides relatively long-term variability and help as an additional evaluation of the amplitude tremors in voice. Considering the above finding the higher SAPQ values obtained in the developmental speech and language disordered delayed populations when compared to normals can be attributed to the inability to maintain constant intensity in phonation.

In cerebral palsy group the fluctuations in frequency and intensity may be indicative of improper functioning of intrinsic laryngeal structure in making the fine adjustment of vocal cords for phonation.

The findings with respect to autistic population can be attributed to fluctuations in vocal volume resulting in loudness levels fluctuating from whispering, muttering and loud ejaculations as supported by Goldfarb et.al., 1956; Pronovost et.al., 1966. . This may be an attempt to reduce auditory feedback and poor volume control due to an inability to perceive and interpret social and contextual cues.

With respect to the findings in autistics increased SAPQ values as described could be attributed to hoarseness and breathy voice quality exhibited, due to tremors in the voice and inability to maintain a constant loudness in phonation. Thus it was concluded that SAPQ could differentiate between normals and developmental speech and language disordered groups.

19. Peak Amplitude Variation (VAm):

The mean and SD values of Vam for |a|, |i| and |u| in normals and the developmental speech and language disordered groups are shown in Tables - XIX(a) and XIX(b).

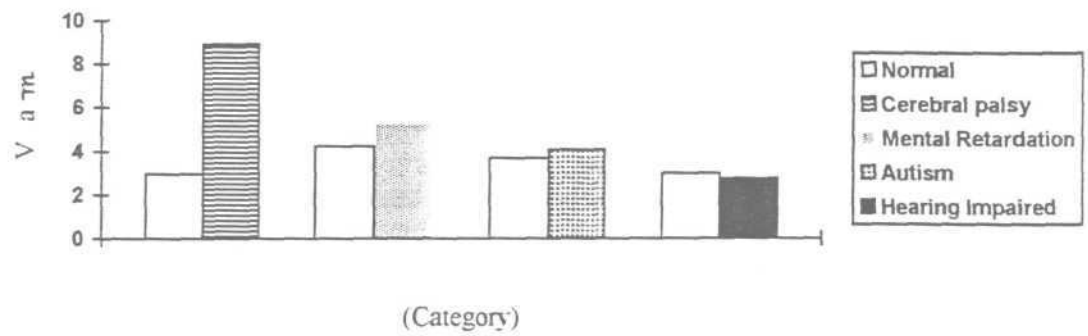
TABLE - XIX(a) : Mean and SD values of Peak Amplitude Variation (Vam) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels |a|, |i| and |u|.

Category (MF)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M)	1.20	0.67	2.10	(0.35)	(0.20)	(1.02)	-	+	+
Cerebral (M) Palsv(M)	1.33	8.93	13.20	(0.45)	(4.17)	(7.51)			
Normal (M)	0.96	2.38	1.64	(0.20)	(1.66)	(0.87)	-	-	+
Mental Retardation *(M)*	0.90	2.57	9 22	(0.34)	(1.76)	(4.27)			
Normal (M)	1.55	1.90	1.90	(0.92)	(0.88)	(0.54)	-	+	+
Autism (M)	1.94	7.55	6.72	(0.92)	(3.57)	(1.23)			
Normal (F)	1.04	0.55	0.76	(0.15)	(0.02)	(0.06)	-	-	-
Autism (F)	1.10	0.92	0.76	(0.16)	(0.08)	(0.06)			
Normal (M)	1.09	1.54	1.53	(0.36)	(0.25)	(0.55)	-	+	-
Hearing Impaired (M)	1.87	5.05	1.99	(0.52)	(0.93)	(0.52)			
Normal (F)	1.10	0.55	1.75	(0.06)	(0.07)	(0.43)	-	-	-
Hearing Impaired (F)	1.96	0.69	1.99	(0.97)	(0.02)	(0.75)			

TABLE - XIX(b): Mean and SD values of Peak Amplitude Variation (Vam) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	S.D.	Significance
Normal (Ctrl)	2.96	(1.15)	+
Cerebral Palsy (Exp)	8.92	(3.94)	
Normal (Ctrl)	4.23	(2.21)	-
Mental Retardation (Exp)	5.31	(1.68)	
Normal (Ctrl)	3.69	(1.24)	-
Autism (Exp)	4.09	(1.57)	

Category	Mean	S.D.	Significance
Normal (Ctrl)	3.00	(3.09)	-
Hearing Impaired (Exp)	2.75	(0.75)	
Total of Normal group	2.20	(2.13)	-
Total of Experimental Group	1.88	(0.58)	



Normal controls of respective abnormal populations

Graph - XVII : Comparison of Normal vs Developmental Speech and Language disordered groups in terms of Peak Amplitude variation.

It can be seen from the tables - XIX(a) and XIX(b) that the cerebral palsied group (all males) showed higher Vam values for |i| and |u| than then normal controls, results tending significant at $P < 0.05$ level. Comparing cerebral palsy as a group (both males and females toegether) higher VAm values were seen for vowels when compared to normals, results significant at $P < 0.05$ level. No significant differences were seen for |aj.

Comparing the normals with the mentally retarded (all males), it can be seen that higher vAm values were seen for |j| when compared to their normal controls results significant at $P < 0.05$ level. Significant group differences were seen for |i| and |u| comparing the normals with the autistic group (all males), results significant at $P < 0.05$ level. No significant group differences were seen for |a|.

TABLE - XX(a) : Mean and SD values of Amplitude Tremor Intensity Index (ATRI) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels |a|, |i| and |u|.

Category (Mi)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M)	0.32	0.15	0.58	(0.09)	(0.05)	(0.16)	-	-	+
Cerebral (M) Palsv(M)	0.13	0.14	1.14	(0.01)	(0.11)	(0.76)			
Normal (M)	0.20	0.60	0.00	(0.16)	(0.25)	(0.00)	-	-	-
Mental Retardation *(M)*	0.31	0.26	0.00	(O.H)	(0.14)	(0.00)			
Normal (M)	0.29	0.60	0.60	(0.12)	(0.26)	(0.12)	-	-	-
Autism (M)	0.58	0.90	0.47	(0.23)	(0.41)	(0.03)			
Normal (F)	0.26	0.07	0.36	(0.08)	(0.01)	(0.21)	-	-	-
Autism (F)	0.21	0.34	0.27	(0.03)	(0.11)	(0.01)			
Normal (M)	0.25	0.26	0.93	(0.05)	(0.03)	(0.64)	-	-	-
Hearing Impaired (M)	0.26	0.20	0.70	(0.09)	(0.02)	(0.36)			
Normal (F)	0.32	0.20	0.93	(0.10)	(0.06)	(0.53)	-	-	-
Hearing Impaired (F)	0.52	0.36	0.70	(0.07)	(0.15)	(0.46)			

TABLE - XX(b) : Mean and SD values of Amplitude Tremor Intensity Index (ATRI) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	**S.D.**	Significance
Normal (Ctrl)	0.51	(0.21)	-
Cerebral Palsy (Exp)	0.13	(0.08)	
Normal (Ctrl)	0.39	(0.02)	-
Mental Retardation (Exp)	0.36	(0.12)	
Normal (Ctrl)	0.72	(0.01)	-
Autism (Exp)	0.66	(0.23)	

Females autistic subjects showed no significant group difference for |a| |i| and |u| when compared to normal controls. Comparing the normals and hearing impaired subjects higher vAm values wre seen for |i|, hearing impairments results significant at P < 0.05 level. There were no significant group differences for |a| and |u|. However, comparing the autistic group as a whole (both males and females together), no signficant differences were seen for vowels.

Hearing impaired females showed no significant group differences for vAm when compared to normal controls. Comparing the hearing impaired subjects as a whole (both males and females together) with normals, no significant group differences were seen.

Thus the null hypothesis stating that there is no significant difference in terms of peak amplitude variation (vAm) between the normal subjects and subjects of the developmental speech and language disordered groups of cerebral palsy, mental retardation, autism, hearing impairment has been rejected partially rejected.

vAm reflects in general the peak-to-peak amplitude variations (short term to long term) within the analyzed voice sample. vAm reveals variations in the cycle-to-cycle amplitude of the voice and Vam values increases regardless of whether the type of amplitude variation is either random or regular short term or long term.

The findings in the disordered populations as discussed above reflects the inability to maintain constant vocal intensity, which reflects a maturational delay of the vocal tract, when compared to their normal controls. It was concluded that peak amplitude variation was useful in differentiating the developmental speech and language disordered populations from normals.

20. Amplitude Tremor Intensity Index (ATRT):

The mean and SD values of ATRI in both normals and subjects of the developmental speech and language disordereed groups of cerebral palsy, mental retardation, autism hearing impairment are shown in Tables XX(a) and XX(b).

TABLE - XX(a) : Mean and SD values of Amplitude Tremor Intensity Index (ATRI) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels **|a|,** |i| and |u|.

Category (M.F)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M) Cerebral Palsv(M) (M)	0.32 0.13	0.15 0.14	0.58 1.14	(0.09) (0.01)	(0.05) (0.11)	(0.16) (0.76)	-	-	+
Normal (M) Mental Retardation *(M)*	0.20 0.31	0.60 0.26	0.00 0.00	(0.16) (0.11)	(0.25) (0.14)	(0.00) (0.00)	-	-	-
Normal (M) Autism (M)	0.29 0.58	0.60 0.90	0.60 0.47	(0.12) (0.23)	(0.26) (0.41)	(0.12) (0.03)	-	-	-
Normal (F) Autism (F)	0.26 0.21	0.07 0.34	0.36 0.27	(0.08) (0.03)	(0.01) (0.11)	(0.21) (0.01)	-	-	-
Normal (M) Hearing Impaired (M)	0.25 0.26	0.26 0.20	0.93 0.70	(0-05) (0.09)	(0.03) (0.02)	(0.64) (0.36)	-	-	-
Normal (F) Hearing Impaired (F)	0.32 0.52	0.20 0.36	0.93 0.70	(0.10) (0.07)	(0.06) (0.15)	(0.53) (0.46)	-	-	-

TABLE - XX(b) : Mean and SD values of Amplitude Tremor Intensity Index (ATRI) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	**S.D.**	Significance
Normal (Ctrl) Cerebral Palsy (Exp)	0.51 0.13	(0-21) (0.08)	-
Normal (Ctrl) Mental Retardation (Exp)	0.39 0.36	(0.02) (0.12)	-
Normal (Ctrl) Autism (Exp)	0.72 0.66	(0.01) (0.23)	-

Category	Mean	S.D.	Significance
Normal (Ctrl)	0.62	(0.27)	-
Hearing Impaired (Exp)	0.57	(0.32)	
Total of Normal group	0.62	(0.31)	
Total of Experimental Group	0.73	(0.65)	

It can be seen from Tables XX(a) and XX(b) that there are no significant group differences betwen the developmental speech and language disordered groups and their respective controls in terms of ATRI values for vowels |a|, |i| and |u|.

Thus the null hypothesis stating that there are no significant differences in terms of amplitude tremor intensity index (ATRI) between normal subjects and the subjects of the developmental speech and language disordered groups of cerebral palsy, mental retardation, autism, hearing impairment is accepted.

21. Noise to Harmonic Ratio (NHR) :

The mean and SD values of NHR for |a|, |i| and |u| in both normals and developmental speech and language disordered groups have been shown in Tables - XXI(a) and XXI(b).

TABLE - XXI(a) : Mean and SD values of Noise to Harmonic Ratio (NHR) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels |a|, \i\ and |u|.

Category (RF)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M)	0.24	0.12	0.20	(0.03)	(0.01)	(0.14)	-	-	-
Cerebral (M) Palsy (M)	0.14	0.11	0.22	(0.02)	(0.01)	(0.03)			
Normal (M)	0.16	0.15	0.23	(0.03)	(0.04)	(0.01)	-	-	-
Mental Retardation (M)	0.15	0.14	0.10	(0.02)	(0.04)	(0.01)			

Category (MF)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M) Autism (M)	0.19 0.27	0.11 0.11	0.11 0.18	(0.01) (0.07)	(0.04) (0.02)	(0.01) (0.06)	-	-	-
Normal (F) Autism (F)	0.12 0.15	0.12 0.12	0.16 0.16	(0.02) (0.02)	(0.01) (0.03)	(0.03) (0.02)	-	-	-
Normal (M) Hearing Impaired (M)	0.20 0.16	0.09 0.14	0.18 0.18	(0.01) (0.01)	(0-01) (0.02)	(0.12) (0.01)	-	-	-
Normal (F) Hearing Impaired (F)	0.14 0.13	0.09 0.17	0.18 0.18	(0.08) (0.02)	(0.04) (0.02)	(0.02) (0.01)	-	-	-

TABLE - XXI(b) : Mean and SD values of Noise to harmonic Ratio (NHR) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	S.D.	Significance
Normal (Ctrl) Cerebral Palsy (Exp)	0.22 0.18	0.07 0.12	-
Normal (Ctrl) Mental Retardation (Exp)	0.07 0.13	(0.04) (0.03)	-
Normal (Ctrl) Autism (Exp)	0.14 0.17	(0.03) (0.10)	-
Normal (Ctrl) Hearing Impaired (Exp)	0.14 0.17	(0.08) (0.11)	-
Total of Normal group Total of Experimental Group	0.15 0.16	(0.07) (0.10)	-

It can be seen from Tables - XXI(a) and XXI(b) that there were no significant group differences in terms of NHR values for |a|, |i| and |u| when the developmental speech and language disordered groups of cerebral palsy mental retardation, autism and hearing impairment were compared to their respective normal controls. The same results were observed for vowels when each disorder as a whole was compared to their normal controls. Thus the null hypothesis stating that there is no significant differences in terms of noise to harmonic ratio (NHR) between the normal subjects and subjects of the developmental speech and language disordered groups of cerebral palsy, mental retardation, autism, hearing impairment was accepted.

22. Voice Turbulence Index (VTI) :

The mean and SD values of VTI in both the normal and developmental speech and language disordered groups of cerebral palsy, mental retardation, autism and hearing impaired is shown in Tables XXII(a) and XXII(b).

TABLE - XXII(a) : Mean and SD values of Voice Turbulence Index (VTI) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels |a|, |i| and |u|.

Category (MF)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M)	0.17	0.05	0.04	(0.08)	(0.01)	(0.01)	-	-	-
Cerebral (M) Palsy (M)	0.10	0.06	0.17	(0.02)	(0.01)	(0.02)			
Normal (M)	0.10	0.08	0.04	(0.01)	(0.04)	(0.01)	-	-	-
Mental Retardation (M)	0.08	0.05	0.04	(0.01)	(0.02)	(0.01)			
Normal (M)	0.13	0.05	0.05	(0.03)	(0.01)	(0.01)	-	-	-
Autism (M)	0.17	0.03	0.05	(0.01)	(0.02)	(0.03)			
Normal (F)	0.10	0.03	0.04	(0.02)	(0.01)	(0.01)	-	-	-
Autism (F)	0.09	0.05	0.04	(0.06)	(0.04)	(0-01)			
Normal (M)	0.14	0.04	0.05	(0.08)	(0.01)	(0.01)	-	-	-
Hearing Impaired (M)	0.09	0.06	0.07	(0.02)	(0.01)	(0.01)			
Normal (F)	0.12	0.04	0.06	(0.05)	(0.02)	(0.01)	-	-	-
Hearing Impaired (F)	0.07	0.04	0.03	(0.02)	(0.01)	(0.01)			

TABLE - XXn(b): Mean and SD values of Voice Turbulence Index (VTI) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	S.D.	Significance
Normal (Ctrl)	0.09	(0.01)	-
Cerebral Palsy (Exp)	0.17	(0.03)	
Normal (Ctrl)	0.07	(0.03)	-
Mental Retardation (Exp)	0.09	(0.02)	
Normal (Ctrl)	0.06	(0.03)	-
Autism (Exp)	0.07	(0.02)	
Normal (Ctrl)	0.07	(0.05)	-
Hearing Impaired (Exp)	0.06	(0.02)	
Total of Normal group	0.07	(0.05)	-
Total of Experimental Group	0.07	(0.06)	

It can be seen from the Tables - XXII(a) and XXII(b) that there were no significant group differences between the developmental speech and language disordered groups of cerebral palsy, mental retardation autism and hearing and their respective control on VTI measure for ;a|, |i| and |u|. Thus the null hypothesis stating that thre is no significant difference in terms of VTI between the normal subjects and subjects of the developmental speech and language disordered groups of cerebral palsy mental retardation autism hearing impairment has been accepted.

23. Soft Phonation Index (SPI) :

The mean and SD values of SPI values for |a, |i| and |u| in normals and the developmental speech and language disorders of cerebral palsy mental retardation autism and hearing impaired are shown in Tables - XXIII(a) and XXIII(b).

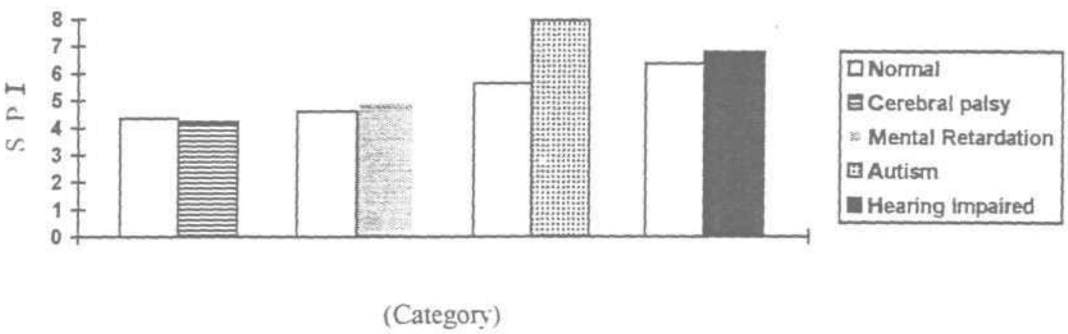
TABLE - XXIII(a) : Mean and SD values of Soft Phonation Index (SPI) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels |a|, |i| and |u|.

Category- (M,F)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M) Cerebral (M) Palsy (M)	3.16 3.70	4.66 5.61	3.97 3.28	(0.85) (1.41)	(1.37) (1.42)	(1.32) (1.36)	-	-	-
Normal (M) Mental Retardation (M)	3.52 3.36	7.81 7.56	4.91 5.23	(0.71) (0.83)	(3-64) (1.67)	(1.58) (0.82)	-	-	-
Normal (M) Autism (M)	3.30 9.43	6.88 11.00	6.88 6.52	(0.88) (3.31)	(1.47) (5.47)	(1.47) (3.05)		-	-
Normal (F) Autism (F)	2.81 6.51	7.81 7.04	6.76 11.78	(0.33) (3.51)	(2.63) (3.81)	(3.18) (4.65)	+	-	+
Normal (M) Hearing Impaired (M)	3.10 3.52	3.10 4.63	4.02 10.67	(0.50) (0.52)	(3.73) (1.84)	(0.62) (7.80)	-	-	+
Normal (F) Hearing Impaired (F)	2.57 3.03	6.09 5.26	4.02 10.60	(0.09) (0.24)	(0.75) (0.59)	(0.67) (7.80)	-	-	+

TABLE - XXm(b) : Mean and SD values of Soft Phonation Index (SPI) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	S.D.	Significance
Normal (Ctrl) Cerebral Palsy (Exp)	4.36 4.23	1.67 1.51	-
Normal (Ctrl) Mental Retardation (Exp)	4.62 4.95	(1.66) (2.58)	-
Normal (Ctrl) Autism (Exp)	5.64 7.95	(2.13) (4.16)	+

Category	Mean	S.D.	Significance
Normal (Ctrl)	6.36	(3.28)	-
Hearing Impaired (Exp)	6.80	(2.48)	
Total of Normal group	6.47	(4.32)	-
Total of Experimental Group	6.01	(3.18)	



Normal controls of respective abnormal populations

Graph - XVIII: Comparison of Normal vs Developmental Speech and Language disordered groups in terms of Soft Phonation Index.

It can be seen from the tables - XXIII(a) and XXHI(b) there were no significant group differences in SPI values for Jaj, |i| and ju| when the cerebral palsy and mentally retarded (males and females separately and as a group) were compared to their respective normal controls.

Comparing the normals and autistic subjects males showed higher SPI values for |a| and |u| when compared to their normal controls results significant at P < 0.05 level. Female autistic subjects also showed higher SPI values for |a| and |u| when compared to their normal controls, results significant for |a|-and |u| at P < 0.05 level.

Comparing the normals and hearing impaired subject, hearing impaired (both males and females) showed higher SPI values for |u| when compared to their normal controls, results significant at 0.05 level. No significant group differences were seen for |ai and |i|. Comparing each of the disordered populations as a whole (both males and females), with their normal controls higher SPI values were seen for vowels in autistic group, results significant at P < 0.05 level.

Thus the null hypothesis stating that there is no significant difference in terms of SPI for |a|, |i| and |u| between the normal subjects and subjects of the developmental speech and language disordered groups of cerebral palsy, mental retardation, autism, hearing impairment was partially rejected.

SPI measures gives the average ratio of the lower frequency harmonic energy (70 - 1600) Hz to the higher frequency (1600 - 4500) Hz harmonic energy. Increased SPI measures as indicated in the findings of the disordered population may be an indicative of incompletely or loosely adducted vocal folds during phonation which could be attributed to a maturational lag in the vocal system. It was concluded that soft phonation index can be used to differentiate the developmental speech and language disordered groups from normals.

24. Degree of Voice Breaks (DVB):

The mean and SD deviation values of DVB for |a|, |i| and |u| in both the normal and developmental speech and language disordered groups have been shown in tables - XXIV(a) and XXIV(b).

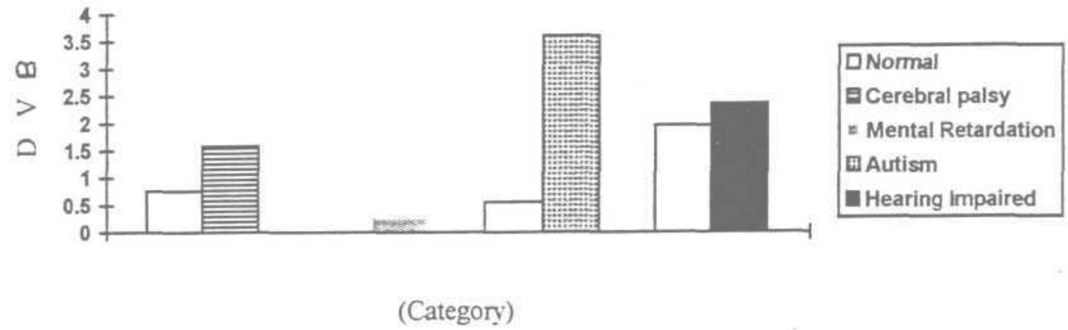
TABLE - XXIV(a) : Mean and SD values of Degree of Voice Breaks (DVB) in both normals and developmental speech and language disordered groups (males and'or females) for the vowels |a|, |i| and |u|.

Category- (MF)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)	-	-	+
Cerebral (M) Palsy (M)	0.00	0.00	2.51	(0.00)	(0.00)	(0.17)			
Normal (M)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)	-	-	-
Mental Retardation (M)	0.00	0.78	0.00	(0.00)	(0.18)	(0.00)			
Normal (M)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)	+	-	+
Autism (M)	8.77	0.00	5.14	(3.59)	(0.00)	0.14)			

Category (M,F)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (F)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)	-	-	
Autism (F)	0.00	0.00	10.04	(0.00)	(0.00)	(3.61)			
Normal (M)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)	-	-	-
Hearing Impaired (M)	0.00	0.35	0.00	(0.00)	(0.07)	(0.00)			
Normal (F)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)	-	-	-
Hearing Impaired (F)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)			

TABLE - XXIV(b): Mean and SD values of Degree of Voice Breaks (DVB) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	S.D.	Significance
Normal (Ctrl)	0.76	(0.51)	+
Cerebral Palsy (Exp)	1.58	(1.09)	
Normal (Ctrl)	0.00	(0.00)	-
Mental Retardation (Exp)	0.26	(0.09)	
Normal (Ctrl)	0.55	(0.31)	+
Autism (Exp)	3.61	(1.27)	
Normal (Ctrl)	1.96	(0.93)	-
Hearing Impaired (Exp)	2.36	(0.66)	
Total of Normal group	0.07	(0.05)	+
Total of Experimental Group	2.16	(1.51)	



Normal controls of respective abnormal populations

Graph - XIX : Comparison of Normal vs Developmental Speech and Language disordered groups in terms of Degree of Voice Breaks.

The above Tables - XXIV(a) and XXIV(b) shows that cerebral palsy (all males) showed higher DVB value for |u|, results significant at P < 0.05 level. Comparing the cerebral palsy group as a whole (both males and females together), higher DVB values were seen for vowels, results significant at P < 0.05 level.

Comparing the normals and mentally retarded group, it can be seen that mentally retarded (all males) showed higher DVB value for |i| when compared to normal controls although results were not significantly different.

Comparing the normals and autistic group, males showed higher DVB values for |a| and |u|, when compared to normal controls results significant at P < 0.05 level. No significant group differences wee seen for |i|. Female autistic subjects showed higher DVB value for |u| (results significant at P < 0.05 level) when compared to their normal controls. No significant group differences were seen for |a| and |i|. Comparing the autistic group as a whole (both males and females together) with normals, higher DVB values were seen for vowels, results significant at P < 0.05 level. Comparing normals and hearing impaired populations no significant differences were seen for vowels on the measure of DVB.

Thus the null hypothesis stating that there is no significant differences in terms of degree of voice breaks for vowels |a|, |i| and |u| between the normal subjects and subjects of the developmental speech and language disordered groups of cerebral palsy, mental retardation, autism, hearing impairment was partially rejected. *DVB* measures the ability of the voice to sustained uninterrupted voicing, Zero indicates normal voice during sustained voicing. Higher DVB values seen for abnormal populations discussed in the findings indicates the presence of voice breaks resulting in inability to maintain uninterrupted voicing in a continuous voice segment. Thus it was concluded that the parameter degree of voice breaks can differentiate developmental speech and language disordered groups from normals.

25. Degree of Subharmonic Segments (DSH):

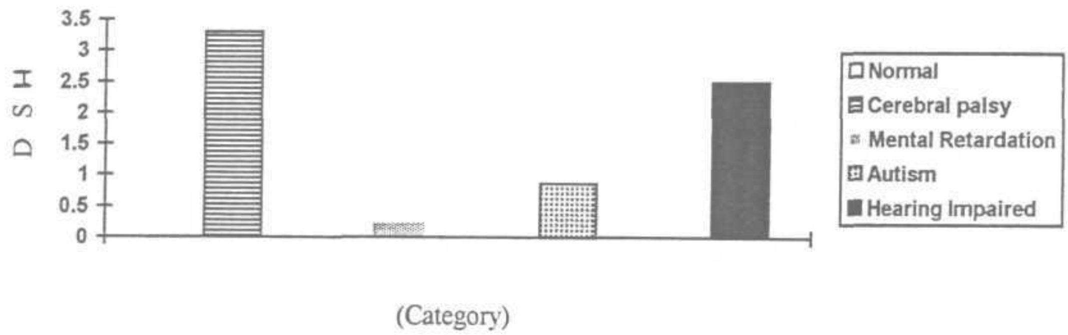
The mean and SD of DSH for |a|, |i| and |u| in the normals and developmental spech and language disordered populations have been shown in Tables - XXV(a) and XXY(b).

TABLE - XXV(a) : Mean and SD values of Degree of Subharmonic Segments (DSH) in both normals and developmental speech and language disordered groups (males and or females) for the vowels |a|, |i| and u|.

Category (MJF)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)	-	-	+
Cerebral Palsv(M) (M)	0.00	0.00	6.67	(0.00)	(0.00)	(2.21)			
Normal (M)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)	-	-	-
Mental Retardation (M)	0.75	0.00	0.00	(0.00)	(0.00)	(0.00)			
Normal (M)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)	-	-	+
Autism (M)	0.00	0.00	3.41	(0.00)	(0.00)	(1.96)			
Normal (F)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)	-	-	+
Autism (F)	0.00	0.00	1.00	(0.00)	(0.00)	(0.41)			
Normal (M)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)	-	-	-
Hearing Impaired (M)	0.00	1.81	0.00	(0.00)	(0.23)	(0.00)			
Normal (F)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)	+	-	-
Hearing Impaired (F)	1.96	0.00	0.00	(0.77)	(0.00)	(0.00)			

TABLE - XXV(b): Mean and SD values of Degree of Subharmonic Segments (DSH) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	S.D.	Significance
Normal (Ctrl)	0.00	(0.00)	+
Cerebral Palsy (Exp)	3.30	(1.23)	
Normal (Ctrl)	0.00	(0.00)	-
Mental Retardation (Exp)	0.25	(0.18)	
Normal (Ctrl)	0.00	(0.00)	-
Autism (Exp)	0.87	(0.22)	
Normal (Ctrl)	0.00	(0.00)	+
Hearing Impaired (Exp)	2.50	(1.29)	
Total of Normal group	0.00	(0.00)	+
Total of Experimental Group	1.72	(0.53)	



Normal controls of respective abnormal populations

Graph - XX : Comparison of Normal vs Developmental Speech and Language disordered groups in terms of Degree of Subharmonic Segments.

It can be seen from the Tables - XXV(a) and XXV(b) that cerebral palsied group (all males) showed higher DSH values for |u| when compared to their normal controls, results significant at P < 0.05 level. Comparing the cerebral palsy group as a whole (both males and females together) with normals, higher DSH values were observed for vowels, results significant at P < 0.05 level.

Comparing normals and mentally retarded group (all males), higher DSH value was seen for |a| when compared to their normal control subjects although results were not significant.

Comparing the normals and autistics, males showed higher DSH value for |u|, results significant at P < 0.05 level. Female autistics showed higher DSH values for |u| when compared to normal control subject, results significant at P < 0.05 level.

Comparing hearing impaired (males and females) with normals, males showed higher DSH value for |i| and females for |a|, results significant at P < 0.05 level. Considering each of the disordered populations as a whole (both males and females together), with normals higher DSH values for vowels were seen in the cerebral palsy and hearing impaired groups, results significant at P < 0.05 level.

Thus the null hypothesis stating that there is no significant difference in terms of DSH between normal subjects and subject of the developmental speech and language disordered groups of cerebral palsy mental retardation, autism and hearing impairment was partially rejected. Higher DSH values in the disordered populations indicate unstable voice quality. It was concluded that this parameter can differentiate developmental speech and language disordered groups from normals.

26. Degree of Unvoiced Segments (DUV) :

The mean and SD of DUV for |a|, |i| and |u| in both normals and subjects of the developmental speech and language disordered groups is shown in tables - XXVI(a) and XXVI(b).

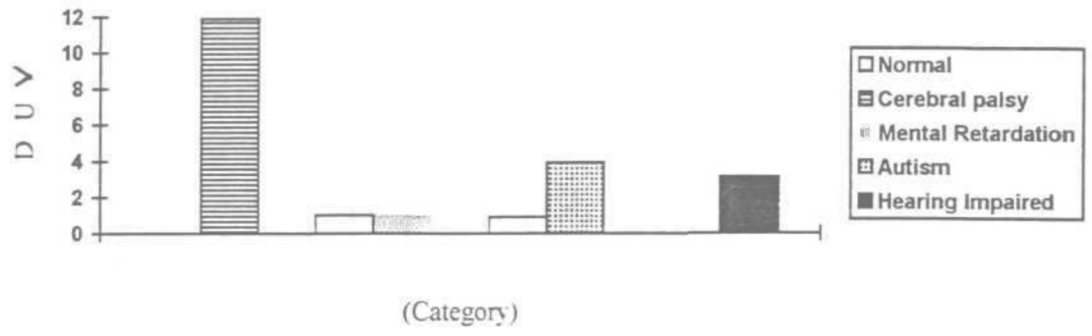
TABLE - XXVI(a) : Mean and SD values of Degree of Unvoiced Segments (DUV) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels |a|, |i| and |u|.

Category (MF)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M)	0.00	O.OO	6.64	(0.00)	(0.00)	(3.75)	+	+	+
Cerebral (M) Palsy (M)	7.25	13.89	13.73	(3.55)	(4.31)	(3.71)			
Normal (M)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)		+	-
Menial Retardation (M)	6.94	8.46	0.00	(1.71)	(2.18)	(0.00)			
Normal (M)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)	+	-	+
Autism (M)	9.82	0.00	4.66	(4.16)	(0.00)	(2.23)			
Normal (F)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)	-	-	-
Autism (F)	0.00	0.42	6.43	(0.00)	(0.00)	(3.21)			
Normal (M)	0.00	O.OO	0.00	(0.00)	(0.00)	(0.00)	-	-	-
Hearing Impaired (M)	0.00	0.42	0.00	(0.00)	(0.16)	(0.00)			
Normal (F)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)	-r	-	-
Hearing Impaired (F)	10.77	0.00	0.00	(5.23)	(0.00)	(0.00)			

TABLE - XXVI(b) : Mean and SD values of Degree of Unvoiced Segments (DUV) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	S.D.	Significance
Normal (Ctrl)	0.00	(0.00)	+
Cerebral Palsy (Exp)	11.90	(6.56)	
Normal (Ctrl)	1.00	(0.89)	-
Mental Retardation (Exp)	1.13	(1.10)	
Normal (Ctrl)	0.91	(0.86)	+
Autism (Exp)	3.93	(1.43)	

Category	Mean	S.D.	Significance
Normal (Ctrl)	0.00	(0.00)	+
Hearing Impaired (Exp)	3.11	(1.00)	
Total of Normal group	0.47	(0.15)	+
Total of Experimental Group	4.02	(2.10)	



Normal controls of respective abnormal populations

Graph - XXI : Comparison of Normal vs Developmental Speech and Language disordered groups in terms of Degree of Unvoiced Segments.

It can be seen from the Tables - XXVI(a) and XXVI(b) that the cerebral palsied group (all males) showed higher DUV values for |a|, |i| and |u| when compared to their normal control subjects, results significant at $P < 0.05$ level. Considering cerebral palsy as a group (both males and females together) with normals, higher DUV values were seen for vowels, results significant at $P < 0.05$ level.

Comparing the normal and mentally retarded (males), higher DUV values wre seen for |a| and |i| when compared to normal control subjects, results significant at $P < 0.05$ level. No significant group differences were seen for |u|. Considering the mentally retarded group as a whole and normals, no significant group differences for vowels was seen.

Comparing the normals and autistics, males showed higher DUV values for |a| and ju|, when compared to their normal controls, results significant, at P < 0.05 level. No significant group differences were seen for |i|. Female autistic subjects showed higher DUV values for |u| when compared to normal controls results significant at P < 0.05 level.

Comparing normals and hearing impaired males, there were no significant group differences for |a|, |i| and ju|. Female hearing impaired subjects showed higher DUV value for |a| (significant at P < 0.05 level) when compared to normal control subjects. No significant group differences were seen for |ij and |u|.

Comparing each of the development speech and language disordered groups (both males and females together), with normals, higher DUV values were seen for cerebral palsy, autistic and hearing impaired groups, results significant at P < 0.05 level.

Thus the null hypothesis stating there is no significant differences in terms of DUV between the normals subjects and subjects of developmental speech and language disordered groups of cerebral palsy, mental retardation, autism and hearing impairment was partially rejected. It was concluded that greater degree of unvoice segments were seen in the voice of the disordered populations, and this parameters could be used to differentiate between these groups and the normals.

27. Number of Voice Breaks (NVB)

The mean and SD values of NVB for |a|, |i| and |u| in both normals and subjects of the developmental speech and language disordered groups of cerebral palsy, mental retardation, autism and hearing impairment are shown in Table. XXVII(a) andXXVII(b).

TABLE - XXVII(a): Mean and SD values of Number of Voice Breaks (NVB) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels |a|, |i| and |u|.

Category (M.F)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M) Cerebral (M) Palsy (M)	0.00 0.00	0.00 0.00	0.00 0.33	(0.00) (0.00)	(0.00) (0.00)	(0.00) (0.06)	-	-	-
Normal (M) Mental Retardation (M)	0.00 0.00	0.00 0.25	0.00 0.00	(0.00) (0.00)	(0.00) (0.12)	(0.00) (0.00)	-	-	-
Normal (M) Autism (M)	0.00 0.50	0.00 0.00	0.00 0.25	(0.00) (0.28)	(0.00) (0.00)	(0.00) (0.08)	-	-	-
Normal (F) Autism (F)	0.00 0.00	0.00 0.00	0.00 0.50	(0.00) (0.00)	(0.00) (0.00)	(0.00) (0.17)	-	-	-
Normal (M) Hearing Impaired (M)	0.00 0.00	0.00 0.25	0.00 0.00	(0.00) (0.00)	(0.00) (0.11)	(0.00) (0.00)	-	-	-
Normal (F) Hearing Impaired (F)	0.00 0.00	0.00 0.00	0.00 0.00	(0.00) (0.00)	(0.00) (0.00)	(0.00) (0.00)	-	-	-

TABLE - XX\TI(b) : Mean and SD values of Number of Voice Breaks (NVB) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	S.D.	Significance
Normal (Ctrl) Cerebral Palsy (Exp)	0.00 0.25	(0.00) (0.18)	-
Normal (Ctrl) Mental Retardation (Exp)	0.00 0.08	(0.00) (0.23)	-
Normal (Ctrl) Autism (Exp)	0.00 0.31	(0.23) (0.13)	-

Category	Mean	S.D.	Significance
Normal (Ctrl)	1.10	(0.63)	-
Hearing Impaired (Exp)	0.50	(0.17)	
Total of Normal group	0.12	(0.08)	-
Total of Experimental Group	0.62	(0.36)	

It was seen from the Tables- XXVII(a) and XXVII(b) that on comparison of the developmental speech and language disordered groups of cerebral palsy, mentally retardation, autism and hearing impaired with their normal controls, no significant group differences were seen for vowels (when comparing males and females separately and as a group).

Thus the null hypothesis stating that there is no significant difference in terms of number of voice breaks between the normals subjects and subjects of the developmental speech and language disordered groups of cerebral, palsy, mental retardation, autism, hearing impairment was accepted.

28. Number of Subharmonic Segments (NSH) :

The mean and SD values of NSH in both the normal subjects and developmental speech and language disordered subjects of cerebral palsy, mental retardation, autism and hearing impairment have been shown in Tables - XXVIII(a) and XXVIII(b).

TABLE - XXVIII(a) : Mean and SD values of Number of Sub-harmonic Segments (NSH) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels |a|, |i| and |u|.

Category (M,F)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)	-	-	-
Cerebral Palsy (M)	0.00	0.00	0.67	(0.00)	(0.00)	(0.35)			

Category (M.F)	Mean			S.D.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M) Mental Retardation (M)	0.00 0.25	0.00 0.00	0.00 0.00	(0.00) (0.13)	(0.00) (0.00)	(0.00) (0.00)	-	-	-
Normal (M) Autism (M)	0.00 0.00	0.00 0.00	0.00 0.75	(0.00) (0.00)	(0.00) (0.00)	(0.00) (0.25)	-	-	-
Normal (F) Autism (F)	0.00 0.00	0.00 0.00	0.00 0.50	(0.00) (0.00)	(0.00) (0.00)	(0.00) (0.19)	-	-	-
Normal (M) Hearing Impaired (M)	0.00 0.00	0.00 0.25	0.00 0.00	(0.00) (0.00)	(0.00) (0.12)	(0.00) (0.00)	-	-	-
Normal (F) Hearing Impaired (F)	0.00 0.00	0.00 0.00	0.00 0.00	(0.00) (0.00)	(0.00) (0.00)	(0.00) (0.00)	-	-	-

TABLE - XXVIII(b) : Mean and SD values of Number of Sub-harmonic Segments (NSH) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	S.D.	Significance
Normal (Ctrl) Cerebral Palsy (Exp)	0.25 0.08	(0.18) (0.02)	-
Normal (Ctrl) Mental Retardation (Exp)	0.00 0.08	(0.00) (0.01)	-
Normal (Ctrl) Autism (Exp)	0.00 0.08	(0.00) (0.12)	-
Normal (Ctrl) Hearing Impaired (Exp)	0.00 0.61	(0.00) (0.38)	-
Total of Normal group Total of Experimental Group	0.00 0.48	(0.00) (0.21)	-

It can be seen from the Tables XXVIII(a) and XXVIII(b) that, there were no significant group differences in terms of NSH between disordered populations of cerebral palsy, mental retardation, autism and hearing impairment for vowels while comparing males and females separately and as a group with normals controls.

Thus the null hypothesis stating there is no significant difference in terms of number of sub-harmonic segments between the normal subjects and subjects of the developmental speech and language disordered groups of cerebral palsy, mental retardation, autism, hearing impairment was accepted.

29. Number of Unvoiced Segment (NUV):

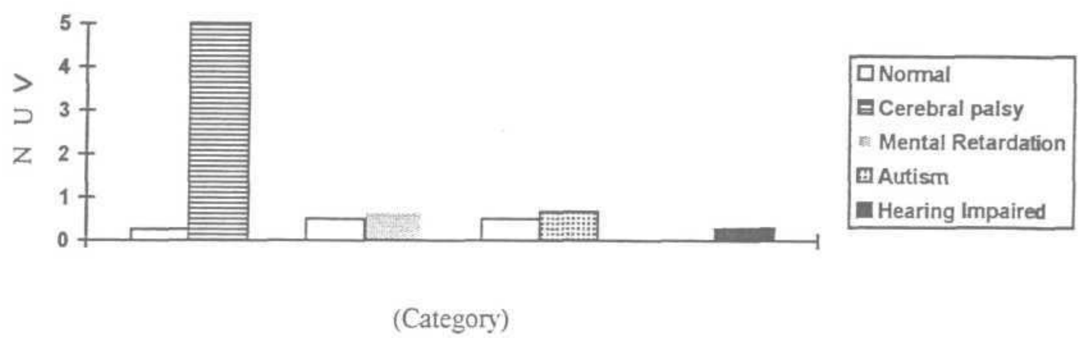
The mean and SD of NUV for |a|, |t| and |u| in both normals and the developmental speech and language disordered groups have been represented in Tables XXIX(a) and XXIX(b).

TABLE - XXIX(a) : Mean and SD values of Number of Unvoiced Segment (NUV) in both normals and developmental speech and language disordered groups (males and/or females) for the vowels |a|, |i| and |u|.

Category (M.F)	Mean			SD.			Significance		
	a	i	u	a	i	u	a	i	u
Normal (M)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)	-	+	+
Cerebral Palsy (M)	1.67	4.33	2.33	(0.98)	(1.24)	(0.73)			
Normal (M)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)	-	-	-
Mental Retardation (M)	1.00	0.00	0.00	(0.67)	(0.00)	(0.00)			
Normal (M)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)	-	-	-
Autism (M)	0.50	0.00	0.25	(0.91)	(0.00)	(0.52)			
Normal (F)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)	-	-	-
Autism (F)	0.00	0.00	0.50	(0.00)	(0.00)	(0.12)			
Normal (M)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)	-	-	-
Hearing Impaired (M)	0.00	0.00	0.00	(0.00)	(0.14)	(0.00)			
Normal (F)	0.00	0.00	0.00	(0.00)	(0.00)	(0.00)	-	-	-
Hearing Impaired (F)	0.00	0.00	0.00	(0.25)	(0.00)	(0.00)			

TABLE - XXIX(b) : Mean and SD values of Number of Unvoiced Segment (NUV) in both normals and developmental speech and language disordered groups for vowels (a, i, u).

Category	Mean	S.D.	Significance
Normal (Ctrl)	0.25	(0.01)	+
Cerebral Palsy (Exp)	5.00	(3.53)	
Normal (Ctrl)	0.50	(0.21)	-
Mental Retardation (Exp)	0.67	(0.37)	
Normal (Ctrl)	0.50	(0.21)	-
Autism (Exp)	0.67	(0.31)	
Normal (Ctrl)	0.00	(0.00)	-
Hearing Impaired (Exp)	0.44	(0.71)	
Total of Normal group	1.58	(0.85)	-
Total of Experimental Group	1.87	(0.69)	



Normal controls of respective abnormal populations

Graph - XXII : Comparison of Normal vs Developmental Speech and Language disordered groups in terms of Number of Unvoiced Segments.

It can be seen from the Tables - XXIX(a) and XXIX(b) that cerebral palsy (all males) showed higher (NUV) values when compared to the normal control subjects, results significant for |a|, ji| and |u| at P < 0.05 level. On comparing the group as a whole (both males and females together) with normals higher NUV values were seen for vowels results significant at P < 0.05 level. Comparing the normal and mentally retarded group, no significant group differences were seen forji| and |u|, although higher value was observed for |a|, significant at P < 0.05 level.

Comparing the normal and autistics subjects males showed higher mean value for |a| and |u| when compared to their normal control subjects, although results were not significant. No group differences were seen for |i|. Female autistic subjects showed no significant group difference for |a|, |i| and |u| when compared to their normal control subjects, however, a slight increase was seen for |u|.

Comparing normals and hearing impaired, no significant group differences were seen when both males and females were compared to their normal subjects. Comparing each of the developmental delayed speech and language disorderes as a whole (males and females together) with normals, higher NUV values were seen for vowels only in the cerebral palsy group, results significant at P < 0.05 level. There were no significant group differences for the other groups.

Thus the null hypothesis stating that, there is no significant difference in terms of NUV for between normal subjects and subjects of developmental speech and language disordered groups of cerebral palsy, mental retardation hearing impairment and their normal controls is partially rejected.

It was concluded that the parameters of NUV could be used in differentiating the disordered populations from normals to some extent.

SUMMARY AND CONCLUSION

Voice is considered as multidimensional series of measurable events.

Acoustic analysis of voice has been considered useful in knowing more about the developmental disorders and thus in treatment of developmental disorders of speech. In many important aspects, the development of motor control for speech is one instance of the more general problem of serially ordered acts, the performance of which is modified to achieve diminishing variability, increased anticipation and improved economy. These attributes are seen highly appropriate to describe the development of motor control for speech (Kent 1980).

Over the past two or three decades considerable research effort has been directed towards obtaining an understanding of the organisation and control of the process by which children learn to produce speech. Such research has involved observations of the aerodynamic and acoustic characteristics of speech. Research background has shown that the vocal parameters of vocal fundamental frequency, static formant patterns of vocalic sounds and timing and coordination of articulation tend to index developmental changes in anatomy, motor control and phonological function.

Based on the above premise, the present study investigated if certain parameters of voice would be sensitive to indicate a maturational delay and enable differential diagnosis of the developmental speech and language disordered populations of cerebral palsy, mental retardation, autism and hearing impairment.

The following twenty nine parameters were chosen for this study as these have been found useful for differential diagnosis of voice disorders.

I. Frequency Parameters:

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 percentage (jitt)
10. Relative average perturbation (RAP)
11. Pitch perturbation quotient (PPQ)
12. Smoothed pitch perturbation quotient (APPQ)
13. Fundamental frequency variation (vFo)
14. Frequency tremor intensity index (FTRI)

II. Intensity Parameters :

1. Shimmer in dB (shdB)
2. Shimmer percent (Shim)
3. Amplitude pertuirbation quotient (APQ)
4. Smoothed amplitude perturbation quotient (SAPQ)
5. Peak amplitude variation (vAm)
6. Amplitude tremor intensity index (A.TRI)

III. Other Parameters :

1. Noise to harmonic ratio (NHR)
2. Voice turbulence index (VTI)
3. Soft phonation index (SPI)
4. Degree of voice breaks (DVB)
5. Degree of subharmonic segment (DSH)
6. Degree of unvoiced segment (DUV)
7. Number of voice breaks (NVB)
8. Number of subharmonic segments (NSH)
9. Number of unvoiced segments (NUV)

These parameters were measured in 4 spastic cerebral paalsied (3 males and 1 female) age ranging 4-13 years, four mentally retarded (4 males) age ranging 7-12 years. 6 autistics (4 males and 2 females) age ranging 4-16 years and 6 Hearing impaired age ranging 4 - 9 years all with delayed speech and language. These parameters were also measured in age and sex matched normal controls for comparisions.

The data was subjected to statistical analysis using computer program SPSS for windows (Version 7.5) to obtain descriptive statistics and non-parameteric test of significance using Wilcoxon Rank signed test.

The following parameters were found useful to differentiate between the normals and few of the developmental speech and language disordered groups.

1. Avereage fundamental frequency (Fo).
2. Highest fundamental frequency (Fhi)
3. Standard deviation of fundamental frequency (STD).
4. Fo tremor frequency (Fftr).
5. Amplitude tremor frequency (Fatr).
6. Absolute Jitt er (Jita);
7. Jitter percentage (jitt)
8. Smoothed pitch period quotient (SPPQ).
9. Fundamental frequency variation (vFo).
10. Shimmer in percent (Shim).
11. Amplitude perturbation Quotient (APQ)
12. Smoothed amplitude perturbation quotient (SAPQ).
13. Peak amplitude variation (vAm).
14. Soft phonation index (SPI).
15. Degree of voice breaks (DVB).
16. Degree of subharmonic segments (DSH).
17. Degree of unvoiced segments (DUV).

Thus the above given parameters could differentiate the voice of the developmental disordered populations from the normals.

Most of these parameters measured variability in frequency, intensity and amplitude in the voice. As variability in acoustic parameters indicated lack of maturation in speech motor control (as supported by Kent 1980), it was concluded that these parameters indicated a delay in the neuromotor speech control in the developmental speech and language disordered groups of cerebral palsy, mental retardation, autism and hearing impairment and thus these measurement would be useful clinically.

Recommendations for further study :

1. Study these parameters on a larger population for generalisation of these findings.
2. Study these parameters in the different disordered groups which are age and sex matched for between group comparisons.
3. Longitudinal study of these parameters in each of the disordered populations.
4. Cross sectional study across the different populations to see age at which stability in these parameters are acquired.

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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.

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

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

$To^{(i)}$ $i = 1,2, \ldots N$ - 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 $Fo = \frac{1}{N} \sum_{i=1}^{N} Fo^{(i)} = \frac{1}{To^{(i)}}$ - Period to period fundamental frequency values.

$To^{(i)}$ $i = 1,2, \ldots N$ - 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 $To^{(l)}$ i = 1,2, ... 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 very 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.

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

"Where $To^{(l)}$, i=l,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 $To^{0)}$, 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 the 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 $To^{(l)}$, i=l,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.

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

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

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 and dB.

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 $A^{(l)}$, 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 $A^{(l)}$, 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.

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 1st 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 nonhannonic 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.

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 $A^{(l)}$, 1=1.2,. . . . . .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 $A^{(l)}$, 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 anah'zed.

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 (VTT)

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.