ACOUSTIC AND PERCEPTUAL CHARACTERISTICS OF VOICE IN NORMALLY AGING ADULT MALES

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A Dissertation Submitted in Part Fulfillment of

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ALL INDIA INSTITUTE OF SPEECH AND HEARING
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CERTIFICATE

This is to certify that this dissertation entitled *"Acoustic and Perceptual Characteristics of Voice in Normally Aging Adult Males"* is the bonafide work submitted in part fulfillment for the degree of Master of Science (Speech-Language Pathology) of the student (Registration N0.O6SLPOO6). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore

April, 2008

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DECLARATION

This is to certify that this dissertation entitled ***"Acoustic and Perceptual Characteristics of Voice in Normally Aging Adult Males"*** is the result of my own study under the guidance of Ms K. Yeshoda, Lecturer, Department of Speech-Language Sciences, All India Institute of Speech and Hearing, Mysore, and has not been submitted in any other university for the award of any diploma or degree.

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CHAPTER I

INTRODUCTION

Voice, as such, is believed to have the ability to convey unique information about the speaker. An individual's voice is affected by a number of factors including cultural expectations, gender-related expectations, personality variables and most importantly aging. Aging is a process that results in a progressive decline of the various control mechanisms needed for daily life, including voice. The topic of aging has been increasingly scrutinized in recent years. Senior citizens are projected to make up an increasingly large segment of the population in the coming years. In recognition of such a demographic shift, voice scientists are endeavoring to develop a database of voice features that are characteristic of normal speakers from young adulthood through old age. Such a database would be invaluable to clinicians struggling to differentiate normal vocal changes due to aging from pathologic vocal conditions affecting elderly patients.

The fact that friends can readily recognize each other's voices over the telephone and that relatives can identify other members of the family from hearing their voices bears testament to the power of the voice in conveying unique information about a speaker. Therefore, it is not surprising that listeners also demonstrate the ability to identify speakers' age with some degree of accuracy simply from hearing a voice sample (Linville, 2001). Although the estimates of speaker's age may be in error, many people believe that they can reliably distinguish elderly speakers from younger adults. For such a differentiation to be possible there must exist differences in the acoustic speech signal between old and younger adults (Gorham-Rowan & Laures-Gore, 2006).

Aging and voice

Aging, per se, may not result in vocal problems but affects the structures of the larynx in varied ways and at varied times during the aging process. Although there is a general trend towards a decline of function in many body systems, the decline may be ameliorated or exacerbated by other factors such as lifestyle, diet, amounts of physical activity, disease or accident. However, geriatric individuals in poor physical condition may experience more communication problems than those in good physical condition.

Kahane (1981a) reported that respiratory capacity and lung function changes with age and contributes to a general decrease in vocal power. Ossification of the larynx was noticed with poor posterior glottic closure due to limitation of movement of arytenoids. Atrophy, edema and increased presence of vocal fold sulci also have been noticed in the larynges of elderly patients. Although the majority of dramatic changes in elderly patients' voices are probably the result of disease processes that occur in association with aging, there are certainly perceptible changes that occur as a result of the normal aging of the mechanism.

Aging of the vocal mechanism

Respiratory changes: The respiratory system changes from young adulthood to old age. In lung tissue, loss of elasticity tends to be the hallmark change associated with aging, usually accompanied by other respiratory system changes such as stiffening of the thorax and weakening of the respiratory muscles. These changes alter the lung volumes and the respiratory mechanics. While the total lung volume remains unchanged in the elderly, maximum expiratory flow rate and lung pressure decreases along with reduction in vital capacity but residual volume increases. Thus, elderly speakers experience a decline in the amount of air they can move in and out of the lungs and the efficiency with which they move air (Ptacek & Sander, 1966).

Laryngeal changes: Various laryngeal changes are believed to occur as an aftermath of aging in the normal aged people. While the main laryngeal alteration documented is the calcification and ossification of the laryngeal cartilages, other important changes have also been reported such as degeneration of the laryngeal muscles and ligaments, reduced tension of the vocal folds as well as thinning and bowing of both the vocal folds (Hoit & Hixon, 1987).

Perceptual and acoustic signs of aging: It is proved that voice of elderly individuals sounds distinctively different. On the whole, listeners are found to do a fairly good job of estimating people's ages on the basis of their speech alone. Perception-based estimates of age rested partly on speaker's articulatory patterns and linguistic usage. Also certain characteristics of the aged voice made a significant contribution to the judgment of a speaker's age (Baken, 2005).

Perceptually, listeners can identify a geriatric voice and can do so from a recorded sample with surprising accuracy. Some of the major features of the geriatric voice include hoarseness, low pitch, imprecise articulation, breathiness and long pauses (Hartman & Danhauer, 1976). According to Ryan & Capadano (1978), the important perceptual feature of the geriatric voice includes pitch, volume, speed, clarity and authority. They also reported that the geriatric voices sounded less clear and less flexible.

Ryan & Burk (1974) opined that vocal characteristics specific to the geriatric voices were: lower vocal pitch, increased hoarseness/harshness, increased strain, vocal tremor, slower speech rate, greater hesitancy, less precise articulation and longer duration of pauses.

It is proved that pitch changes with aging. There may also be a decrease in pitch flexibility and habitual pitch levels with advancing age. Mysak (1959) reported an increase in male pitch level due to aging. However, no age-related trend was noticed in frequency range in phonation for either males or females (Hollien, Dew & Philips, 1976).

Acoustically, there are several features of the voice that change as a result of aging. Some of these are related to intensity, continuity, response time but the most obvious acoustic features of the aging voice pertain to fundamental frequency (F_0) and stability of frequency and amplitude (Baken, 2005). Perhaps the voice change that has been investigated most is fundamental frequency (F_0). In men, F_o lowers approximately 10 Hz from young adulthood to middle age (Brown, Morris, Hicks & Howell, 1991). The reason for this drop is still unclear. After middle age, F_0 in men rises substantially by approximately 35 Hz as age advances further. Hollien & Shipp (1972) have also documented that F_0 tends to rise as a function of age in males.

The intensity of an older voice may be slightly greater than a young voice (Brown, Morris & Michel, 1989). They hypothesized that higher speech intensity in elderly men might be an adaptive mechanism related to findings of decreased laryngeal airway resistance with aging by Hoit & Hixon (1987). However, it seems more plausible that lower airway resistance values in elderly men result in lower speech intensity rather than the opposite. That is, lower airway resistance (related to incomplete approximation of the vocal folds during phonation) would compromise the valving capacity of the laryngeal mechanism, making it more difficult to sustain higher intensity levels during conversation. Thus, elderly men would tend to use lower conversational intensity levels. A definitive answer as to the physiological basis of age-related increases in intensity levels of conversational speech in men awaits further study (Linville, 2001).

Stability of F_0 reportedly declines from young adulthood to old age in both men and women. In men, levels of F_0 standard deviation were more than double between young adulthood and old age. However, Ramig & Ringel (1983) have reported no difference in jitter between young and geriatric subjects. Amplitude stability also declines with aging, at least in men (Biever & Bless, 1989; Ramig & Ringel, 1983; Ringel & Chodzko-Zaiko, 1987).

Another voice quality which is believed to be linked with the aged voice is increased breathiness. While elderly men have been shown to demonstrate a higher incidence of glottal gap than young men, spectral noise levels do not differ in the two groups. However, spectral noise levels tend to increase in men in poor physiological condition, regardless of age (Gorham-Rowan and Laures-Gore, 2006).

Ascertaining the age of speakers

Listeners are able to identify the speakers' age with some degree of accuracy simply hearing a voice sample. The difficulty of the task varies with the precision of the age estimation required – listeners usually find it easier deciding if a speaker is young versus old than identifying the speaker's age. The difficulty of the age estimation task also varies according to the nature of the speech sample presented. For instance, listeners are more accurate in judging age from reading samples played forward than reading samples played backward or normally phonated vowels. In other words, the less the acoustic information present in the sample, more difficult will be the age speculation task for the listener. However, it was opined that the listeners were not reduced to random guessing, even when judging age from samples devoid of voicing information, such as whispered vowels (Linville, 2001).

Another important issue in age estimation of speakers is that although listeners as a whole tend to be accurate in their age estimations of speakers from voice samples, certain factors may affect their accuracy. Linville & Korabic (1986) found that elderly women were not as accurate as young women in perceiving speaker's age from sustained vowels, although the two groups tended to categorize individual speakers similarly. According to Hollien & Shipp (1976), young adulthood and middle age may be the optimum stages of life for judging age using voice samples.

Findings have suggested that listeners were more accurate in their age estimations of young speakers, even if the listeners themselves were elderly (Hollien & Tolhurst, 1978; Jacques & Rastatter, 1990).

The studies in the past have focused on various aspects of voice in normal aging. However, till date, the precise effect of the normal aging process is still not well understood. Therefore it is necessary to document the most salient perceptual and acoustic features of the elderly speakers' voice at different stages of aging which would allow voice specialists to be in a better position to differentially diagnose the normally aging voice from voice changes resulting from pathological conditions. Hence, better decisions about the need for intervention can be made and counseling of the geriatric speaker coming with the complaint of voice problems can be carried out more confidently.

CHAPTER II

REVIEW OF LITERATURE

The effects of aging on voice are predominantly pronounced. According to Ringel & Chodzko-Zaiko (1987), "Aging is an umbrella term covering a wide variety of changes that take place at the molecular, cellular and organ levels, all of which when put together decrease the ability of the body to respond to disruption in its homeostatic equilibrium". Changes related to aging are involuntary, irreversible and cumulative and usually take place gradually. The anatomic, physiologic and neurologic changes that occur normally with aging and its influence on vocal mechanism and voice must be factored into the process of vocal pedagogy.

Research in the field of the aging voice has primarily focused on: ascertaining common perceptual traits of the normally aging individuals, the acoustic variables that represent normal aged voice and estimation of speakers' age.

Influence of age on vocal mechanism

According to Hoit & Hixon (1987) some of the most important age-related changes known to occur in respiratory function were, (i) Changes in structure (increased alveolar duct size, decreased alveolar surface area, calcification of costal cartilages, decreased intervertebral spaces, increased connective tissue and fat cells, increased anteroposterior diameter of lungs, increased anteroposterior diameter of thorax), (ii) Changes in subdivisions of lung volume (decreased vital capacity, decreased inspiratory reserve volume, decreased inspiratory capacity, slightly increased functional residual capacity, decreased expiratory reserve volume, increased reserve volume), (iii) Changes in mechanics (decreased pulmonary recoil pressure, increased pulmonary compliance, decreased chest wall compliance, decreased maximum inspiratory and expiratory pressures, decreased forced expiratory flow, increased closing volumes and capacities), (iv) Changes in ventilation, perfusion and gas exchange (alveolar ventilation becomes less uniform, pulmonary diffusing capacity decreases, arterial oxygen tension decreases, maximal oxygen intake decreases) and (v) Changes in nervous system (degeneration of peripheral nerve fibers, decrease in number of cell bodies in the central nervous system, decreased number of motor units, loss of dendrites, altered neurotransmitter levels, decreased ventilatory responses to hypoxia, decreased sensory perception and discrimination, increased reaction time).

Laryngeal changes due to aging

The major consequence of aging on the larynx is the calcification and ossification of the hyaline cartilages that make up most of its structure. These mineralization processes make the larynx to become more rigid. Ossification can be detected by the age of 20 years and it is believed that complete calcification and ossification occurs by age 65 years (Zemlin, 1968). Other anatomical changes in the larynx such as degenerative changes in the laryngeal muscles and ligaments; laxity, thinning and bowing of the vocal folds and changes in mucous secretion have also been reported (Luschsinger & Arnold 1965; Zemlin, 1968).

Age-related anatomical changes in the larynx are usually more extensive in males compared to females, namely: the ossification and calcification of laryngeal cartilages, atrophy and degeneration of the intrinsic muscles of the larynx, deterioration of cricoarytenoid joint, degeneration of glands in the laryngeal mucosa, degenerative changes in lamina propria and degenerative changes in conus elasticus (Linville, 2001).

In elderly males, changes in the cricoarytenoid joint may affect function by lessening vocal fold approximation or reducing the smoothness of vocal fold adjustments during phonation. Glandular changes may cause drying of epithelium, which may increase stiffness of the vocal fold cover. Increased cover stiffness could increase instability of vocal fold vibration and raise fundamental frequency (F_0) in elderly men. Progressive thickening of the epithelium with aging has also been reported in both sexes. In males, thickening is progressive up to age 70, which declines thereafter. Thickening of the laryngeal epithelium may contribute to lowering of F_0 or to increased harshness of voice (Linville, 2001).

Perceptual characteristics of aging voice

Commonly agreed upon is the fact that "older people sound distinctively different" (Baken, 2005). But the specific perceptual traits underlying the aging voice is a more debatable issue among researchers. Various authors have reported different cues used by listeners in age-identification tasks. The earliest studies (Ptacek & Sander, 1966; Ryan & Capadano, 1978) investigated the perceptual cues of aging voice. Ten listeners have judged the perceptual features of voice of seventy-two speakers and the speakers themselves were asked about any particular changes in their voices observed with aging. Listeners have reported that vocal pitch and vocal tone quality as cues in age identification in both males and females. They judged subjects to have a lower vocal pitch with increasing age. Two-fifths of the aged speakers reported that the pitch of their voices became lower as they got older, although several others also reported an increase in pitch. Of the ten listeners, five reported hoarseness or strain and three reported pitch breaks as characteristics of the aging voice. Pitch variability and reduced loudness were also mentioned.

Ryan & Burk (1974) recorded speech samples of forty speakers between the ages of 40 and 80 years. The recorded samples were played to five speech pathologists for perceptual description. The following perceptual variables represents the ten voice characteristics which were judged to be present often in the voices by the majority of the speech pathologists: 1) air loss, 2) laryngeal tension, 3) vocal fry, 4) pitch breaks, 5) voice tremor, 6) hypernasality, 7) hyponasality, 8) imprecise consonants, 9) slow rate and 10) slow rate of articulation (a noticeable prolongation in vowel or syllable duration throughout an individual speech sample). Findings of the study suggested that the process of aging brings about changes in the speech mechanism that can be described by trained listeners.

Hartman & Danhauer (1976) studied the characteristic perceptual features of voice in subjects between the age of 20 and 60 years. They found low pitch and hoarseness to be present in subjects between 40 to 50 years and 50 to 60 years of age.

Hartman (1979) conducted a study to identify the most common perceptual cues of voice in aging. He identified the most frequent signs of aging to be low pitch, hoarseness, rapid rate, imprecise articulation, slow rate, high pitch and unclear quality (in the given order of occurrence). Analysis of features by perceived age revealed that: rapid rate, high pitch, precise articulation and clear quality appeared to be the best discriminators of speakers judged to be below 30 years. Low pitch, precise articulation, clear quality and moderate pitch appeared to be the dominant indicators for speakers perceived to be between 30 and 40 years; the initial appearance of hoarseness, glottal fry, breathiness and long pauses is also recognized during this period. Low pitch, hoarseness, imprecise articulation and moderate rate appeared to be the most representative features for speakers judged to be between 40 and 50 years. Low pitch, hoarseness, slow rate, imprecise articulation, breathiness and long pauses were the dominant features for speakers perceived to be within the 50 - 60 years age range.

Gorham-Rowan & Laures-Gore (2006) conducted a study in which ten naïve listeners were made to perceptually judge 134 samples for the presence of hoarseness and breathiness. Results supported previous findings of changes in voice function with age. No significant difference in perceived breathiness was found between young and elderly speakers. Similarly, no significant difference was found for perceived hoarseness between young and elderly men while elderly women were perceived as significantly more hoarse than young women.

Acoustic characteristics of aging voice

Research attention has also been devoted to discovering acoustic changes that occur normally in voice with aging. According to Linville (2001), "the acoustic signal leaving the lips of an elderly speaker bears the imprint of having been created by an altered mechanism" – that is, the aging process results in anatomical alterations in the mechanism that affect the functioning of structures responsible for speech production. Alterations in function subsequently affect the sound that is created when speech is produced.

Frequency and Intensity measures: In men, speaking fundamental frequency (SF_0) lowers approximately 10 Hz from young adulthood to middle age (Mysak, 1959; Hollien & Shipp, 1976; Pegoraro Krook, 1988; Brown et al, 1991). After middle age, SF_0 in men rises substantially (approximately 35 Hz) into advanced old age. Thus, a man's SF_0 reaches the highest level of his adult life by about 85 years (Decoster & Debruyne, 1997). SF_0 tends to decrease with increasing maturity in men as age advances to middle age and following which it raises with further increase in age. The effect is greater in men and occurs at an earlier age than in women; that is, the vocal folds of both men and women vibrate more rapidly with advancing age (Baken, 2005).

Ptacek & Sanders (1966) reported that elderly men demonstrate restriction of Maximal Phonational Frequency Range (MPFR) due to loss of the ability to phonate high pitches. Baken (2005) further supported the fact that older people have a more restricted MPFR than younger people.

Ryan (1972) examined speech intensity in 80 men ranging in age from 40 to 79 years from a sample of conversation as well as a reading passage. Results indicated that men over the age of 70 years used higher conversational speech intensity levels than did the younger men during both speaking tasks. He hypothesized that higher speech intensity in elderly men might be an adaptive mechanism related to findings of decreased laryngeal airway resistance with aging.

Intensity range has been investigated as a function of age through examination of maximum intensity vowel productions. Decreased maximum vowel intensity with advanced age has been reported in both males and females. Ptacek & Sander (1966) compared individuals younger than 40 years with those older than 65 years and determined that maximum vowel intensity was reduced 5.3 dB in elderly men and 7.6 dB in elderly women in comparison with their younger counterparts.

Fundamental Frequency Standard Deviation (F_0SD) and Amplitude Standard Deviation (AmpSD) also tend to increase with increasing age. These measures may be a better discriminator of vocal age than jitter and shimmer (Linville & Fisher, 1985; Orkiloff, 1990). Orkiloff (1990) reported substantial differences in F_0SD in men as age increases. He also found that elderly men demonstrated an increase in AmpSD of 54% in comparison with young men. Standard deviations of frequency and amplitude were more than twice between young adults and older subjects. Lower sound pressure levels were seen for older subjects but no significant difference in loudness level modulation was reported.

Perturbation measures (Jitter and Shimmer): According to Linville & Fisher (1985) and Linville (2001), jitter and shimmer do not constitute the best measures for voice in aging individuals. However, both jitter and shimmer have been reported to increase as age advances in individuals.

Other measures: Harmonic-to-Noise Ratio (HNR) quantifies the relative amount of additive noise in the voice signal. Ramig & Ringel (1983) reported that older speakers in poor physical condition showed more spectral noise than older speakers in good physical condition.

Acoustic-perceptual correlation

Acoustic characteristics of the aging voice could be compared to the cues reportedly used by listeners in age identification to arrive at a possible correlation.

Ryan & Burk (1974) found poor correlation when five acoustic measures (dBSPL, words per minute, words per minute per sentence rate, mean fundamental frequency, and standard deviation of fundamental frequency) were compared with the judged voice parameters (air loss, laryngeal tension, vocal fry, pitch breaks, voice tremor, hypernasality, hyponasality, imprecise consonants, slow rate and slow rate of articulation) of the 40 speakers involved in their study.

Gorham-Rowan & Laures-Gore (2006) found no significant correlation between perceived breathiness with any of the investigated acoustic measures (using the Multi

Dimensional Voice Program and TF32). However, a moderate correlation was found between amplitude perturbation quotient and perceived hoarseness.

Age identification based on audition

Several studies have reported on how skilful listeners are in assigning a general chronological age category to a voice, without seeing or knowing the talker.

The first study that attempted quantification of age judgment from voice samples was initiated by Ptacek & Sanders (1966). They recorded two groups of talkers: “old talkers” and “young talkers” with an average age of 75 years and 21 years respectively. Ten observers, of unreported age, were made to listen to randomized samples of the two groups of talkers reading a 53-word passage and sustaining a vowel. The judges’ task was to sort the taped samples into two age groups: under 35 years of age or over 65 years of age. The findings indicated that the judges could sort the reading passages into these age groups with 78% accuracy. It was asserted from this study that listeners could recognize and sort out “old” and “young” voices.

Shipp & Hollien (1969) investigated more refined age identifications by audition. Male speakers ranging in age from 20 to 89 years prolonged a vowel, spoke for one minute and read aloud the first paragraph of the Rainbow Passage (Fairbanks, 1960). Listeners were randomly assigned to one of three groups: the first group judged speaker’s age on a three-point scale, the second group used a seven-point rating scale and assigned a number from 2 to 8 to individual samples and the third group directly estimated the age of the speaker. Results indicated high correspondence between perceived age and chronologic age for all three methods of age estimation. The authors suggested that there is a perceptually identifiable parameter (or set of parameters) in speech samples that can be identified as that belonging to a particular age. They further argued that their findings “quantified an empirical impression that most people are indeed able to estimate a speaker’s age from the voice, perhaps as a result of their constant confrontation with this task throughout their lives, that is, when answering a telephone, listening to a radio, or overhearing the speech of an unseen talker”. Also, they pointed out that “the accuracy and reliability of age estimations by judges suggest that this parameter may be an important one in the process of talker recognition. It could be speculated that the listener, when presented with a voice stimulus, initially classifies the talker on the basis of possible age and then makes additional judgmental refinements in identification, using contextual or other cues”.

Ryan & Capadano (1978) evaluated age estimation for speakers grouped according to sex. Female speakers ranged in age from 12 to 71 years and male speakers ranged from 17 to 68 years. For both genders, significant correlation was found between chronologic and estimated ages indicating a strong relationship between the perceived and actual age of the speakers.

Hartman (1979) investigated whether there is a significant difference in the judgments of untrained male and female listeners in identifying the age of male speakers from spontaneous conversation. Twenty males and twenty females with no prior knowledge of the research were given five seconds to make direct age estimations after listening to each of the 30-seconds samples of continuous speech of 46 male speakers in the age range of 25 - 70 years. Results indicated that both male and female listeners performed similarly when estimating younger individuals' voices but differed significantly when estimating older individuals' voices.

Need for the study

Although the aged population has increased worldwide, the precise effect of the normal aging process is still not well understood. An attempt to document the most salient perceptual and acoustic features of the elderly speakers' voice at different stages of aging will allow the clinician to be in a better position to differentially diagnose the normally aging voice from voice changes resulting from pathological conditions. Hence, better decisions about the need for intervention can be made and counseling of the geriatric clients reporting with the complaint of voice problems can be carried out more confidently.

Further, most research to date has focused specifically on either acoustic or perceptual features of the aging voice while limited studies have dealt with the correlation between both the perceptual and acoustic features of voice in aging. Also in Indian context, there is a lack of information regarding voice changes in aging as most data are being extrapolated from Western studies.

Aims of the study

1. To study the acoustic features of voice in normal adult male speakers.
2. To study the perceptual characteristics of voice in normal adult male speakers.
3. To investigate the correlation, if any, between the perceptual and acoustic characteristics.
4. To investigate listeners' ability to identify the age of the speakers based on voice and speech characteristics.

CHAPTER III

METHOD

SUBJECTS: The subjects comprised of two groups: the speakers and the listeners.

Speakers: A total of 33 normal adult male subjects were selected for the study. They were grouped into four categories based on decade-wise age: 41-50 years, 51-60 years, 61-70 years and 71-80 years. Each age group included 10 subjects except for the last age group which included 3 subjects only.

A detailed subject history and screening was carried out to ensure that all the 33 speakers fulfilled the following criteria:

a) No history of present or past speech, language or hearing problems.

b) No present or history of diabetes, hypertension, respiratory ailments (such as asthma, pneumonia).

c) No neurological, cardiovascular or psychological problems (subjects with good general health condition who were not under medication for the aforementioned medical conditions were preferred for the purpose of the study).

d) None of the subjects were professional voice users or having prior or present vocally abusive behaviors (loud talking, excessive talking).

e) All the subjects were non-smokers and not alcohol consumers at the time of the study (subjects had either no prior history of smoking or had quit smoking by a minimum of 25 years).

f) Subjects were explained the purpose of the study and prior consent was taken before their participation in the study.

Listeners: The listeners who participated in the study were 5 female speech-language pathologists. All the listeners had a Master's degree in Speech-Language pathology and had a minimum of 5 years of clinical experience at the time of their participation in the study.

PROCEDURE

Recording of speech samples

Instructions: All speakers were instructed to take a deep breath and say /a/ as long as possible at a comfortable pitch and loudness level (the task was first demonstrated by experimenter). Then they were instructed to speak continuously for about 2 minutes (about self but exclude any mention of age or reference to age throughout the task).

Task: involved eliciting the following

1. Sustained phonation of the vowel /a/ at comfortable loudness and pitch for a duration of about 6 seconds.
2. Running speech on the topic 'self' for about 2 minutes.

The subjects were comfortably seated and the recording was carried out in a quiet room situation. A sample was obtained from each of the speakers using a digital voice recorder (Olympus Digital Voice Recorder WS-100). The microphone was placed at a distance of 5-6" inches from the speaker's mouth during recording.

Listening experiment

Instructions: Each listener was instructed as follows: "*A voice sample will be played to you. Listen carefully and describe the voice as freely as you can. You will then listen to the speech sample of the same person to whom the voice belonged. Use information from both the voice sample and speech sample and identify the exact age of the subject*".

Tokens: For the listening experiment, the samples of the speakers were converted into tokens. A total of 33 tokens were constructed. Each token consisted of 3 seconds phonation and 30 seconds speech sample drawn from the original 2 minutes speaking sample recorded.

ANALYSIS

The analysis was carried out in two phases: Perceptual analysis and Acoustic analysis.

Perceptual Analysis: Each listener was provided with a response sheet and they judged the tokens individually. The listeners were asked to describe the characteristics of voice after listening to the phonation samples. The listeners identified the exact age of each of the speaker after listening to the phonation and speech samples. No time limit was given for writing down the features or identifying the speaker's age. All the tokens were presented in a randomized fashion. Responses of all the five listeners were pooled decade-wise and compiled according to the commonly used terms to describe perceptual characteristics of voice.

Acoustic Analysis: Phonation samples of all the subjects were line fed into the external module of the CSL 4500 using 44100 Hz. Using MDVP, twenty-nine voice parameters grouped under the major eight categories were extracted.

I. Fundamental frequency information measures: average fundamental frequency (F_0), average pitch period (T_0), highest fundamental frequency (F_{hi}), lowest fundamental frequency (F_{lo}) and standard deviation of fundamental frequency (STD).

II. Short and long-term frequency perturbation measures: absolute jitter (Jita), jitter percent (Jitt), relative average perturbation (RAP), pitch period perturbation quotient (PPQ), smoothed pitch perturbation quotient (sPPQ), fundamental frequency variation (vF_0).

III. Short and long-term amplitude measures: shimmer in dB (ShdB), shimmer percent (Shim), amplitude perturbation quotient (APQ), smoothed amplitude perturbation quotient (sAPQ), peak amplitude variation (vAm).

IV. Voice break related measures: degree of voice breaks (DVB), number of voice breaks (NVB).

V. Sub-harmonic components related measures: degree of sub-harmonics (DSH), number of sub-harmonic segments (NSH).

VI. Voice irregularity related measures: degree of voiceless (DUV), number of unvoiced segments (NUV).

VII. Noise related measures: noise-to-harmonic ratio (NHR), voice turbulence index (VTI), soft phonation index (SPI).

VIII. Tremor related measures: F_0 tremor intensity index (FTRI), amplitude tremor intensity index (ATRI), F_0 tremor frequency (Fftr), amplitude tremor frequency (Fatr).

Statistics

Suitable statistical procedures were adopted to analyze the extracted perceptual and acoustic data. Also the perceptual and the acoustic parameters were analyzed for any possible correlation.

CHAPTER IV

RESULTS AND DISCUSSION

A total of thirty-three male speakers were categorized into four age groups: 41-50 years, 51-60 years, 61-70 years and 71-80 years. Each age group consisted of ten speakers except the fourth age group (71-80 years) where only 3 subjects satisfied the selection criteria. Table 1 shows the number of speakers in each age group and their mean ages.

Age group (years)	No. of speakers	Mean age (years)
41-50	10	43.8
51-60	10	52.9
61-70	10	65.3
71-80	3	77.3

Table 1: Number of speakers in the age groups and their mean ages

SPSS version 10.0 was used for statistical analysis. Mean and standard deviation were extracted. One-way ANOVA was done to find the significance. Duncan's post-hoc test was carried out to find the group correlation. The fourth age group (71 – 80 years) was not considered for the post-hoc analysis due to lesser subject size. Pearson Product-Moment Correlation was used to find correlation between the selected perceptual and acoustic characteristics. The results will be discussed under the following headings,

A. Acoustic analysis

B. Perceptual analysis

C. Correlation between perceptual and acoustic characteristics

D. Identification of age of speakers

A. Acoustic analysis

Twenty-nine parameters grouped under the eight major categories were extracted for all the phonation samples using the Multi-Dimensional Voice Program (MDVP) software. The measures obtained are tabulated in tables 2 to 9.

I Fundamental frequency information measures

Parameter	Age Group (Years)	Mean	Standard Deviation	F	Significance
F_0	41-50 51-60 61-70 71-80	125.483 120.828 125.591 132.767	15.984 18.094 28.354 20.652	0.160	0.853
T_0	41-50 51-60 61-70 71-80	8.077 8.598 8.228 7.677	0.899 1.269 1.438 1.125	0.481	0.624
F_{hi}	41-50 51-60 61-70 71-80	165.437 145.439 162.757 171.035	12.899 13.278 12.538 15.345	0.843	0.441
F_{lo}	41-50 51-60 61-70 71-80	109.222 96.882 95.707 108.997	13.373 12.758 10.886 21.028	0.366	0.039*
STD	41-50 51-60 61-70 71-80	2.992 4.786 5.607 7.330	1.214 2.466 2.702 2.959	3.612	0.041*

Table 2: Mean, standard deviation, F value and significance for fundamental frequency information measures. * significant at a level of 0.05

Table 2 reveals that mean F_0 was least for subjects in 51 - 60 years age group and highest for subjects in 71 - 80 years age group. Though the mean F_0 increased with increase in age, the same was not significant. Highest mean T_0 was seen in 51 - 60 years age group while lowest mean T_0 was seen in 71 - 80 years age group. Mean T_0 was not observed to increase with increasing age. Mean F_{hi} increased with age, being least for subjects in 51 - 60 years group and most of subjects in 71 - 80 years but significance was absent. Mean F_{lo} showed significance at {$F (2, 27) = 0.843; p<0.05$}. Duncan's post-hoc test was done since the parameter was significant. However the last age group (71 - 80 years) was not considered for the post-hoc test due to limited number of subjects in the group. It revealed that F_{lo} was significantly lower in the 41 - 50 years age group compared to both the 51 - 60 and 61 - 70 years age groups. Mean STD parameter also showed significance at {$F (2, 27) = 3.612; p<0.05$}. Duncan's post-hoc test showed that mean STD in the 41-50 years group differed significantly from the 61 - 70 years group only but the mean STD values in the 51 - 60 age groups showed similarities with both other groups.

The mean F_0 values increased gradually 5^{th} decade onwards. This is similar to the findings of Mysak (1959), Peroraro, K. (1988), Hollien & Shipp (1972), Brown et. al. (1991) and Baken (2005). Changes in vocal fold structure and shape as well as increased vocal stiffness could result in such an increase. The above results also indicated that mean STD increased with aging. This is in accordance with the studies of Mysak (1959) who reported increased frequency variability as a hallmark of the aging voice. The mean F_{hi} increased with increasing age and younger individuals tended to have a lower F_{lo}. Both these findings support the possible use of a higher pitch and loss of MPFR in elderly men compared to younger ones as opined by Ptacek & Sanders (1966), Hollien & Shipp (1972) and Baken (2005). Changes in the physical characteristics of the vocal folds are reportedly thought to be reason for changes in F_0 in aged individuals.

II Short and long term frequency perturbation measures

Table 3 indicates that the mean Jita increased with increase in age and showed significance at {F (2, 27) = 3.30; p<0.10}. Duncan's post-hoc test revealed that Jita in the age group of 41 - 50 differed significantly from 61 - 70 years. However, the 51 - 60 years age group showed similarity with both other groups. This suggests considerable increase in mean Jita after 60 years of age. Mean Jitt also showed significance at a similar level of {F (2, 27) = 9.404; p<0.05}. Duncan's post-hoc test suggested that significant increase in Jitt occurs after 6^{th} decade (age group of 61 - 70 years). Lowest mean Jita and Jitt were present in 41 - 50 years age group and highest mean Jita and Jitt were in 71 - 80 years age group. Means of RAP and PPQ also increased with age with lowest mean values in 41 - 50 years age group and highest mean values in 71 - 80 years age group but they were not found to be significant. Mean sPPQ showed significance at a level of {F (2,27) = 2.563; p<0.1}. Duncan's post-hoc test showed significant difference between the age groups of 41 - 50 years and 61 - 70 years which suggests that increase in mean sPPQ was noticed with increased age but was significantly different after 6^{th} decade of life. Mean vF_0 showed significance at a level of {F (2,27) = 3.142 p<0.1}. Duncan's post-hoc test showed major changes in vF_0 to become significant in the age range of 61 - 70 years when compared to other age groups. Both means of sPPQ and vF_0 indicated lowest mean values in the 41 - 50 years age group and highest mean values in the 71 - 80 years age group.

Parameter	Age Group (Years)	Mean	Standard Deviation	F	Significance
Jita	41-50 51-60 61-70 71-80	96.886 169.939 252.040 386.473	74.289 90.041 202.860 187.752	3.30	0.052**
Jitt	41-50 51-60 61-70 71-80	1.247 2.345 3.650 6.230	0.813 1.184 1.598 0.716	9.404	0.001*
RAP	41-50 51-60 61-70 71-80	0.723 0.275 1.524 2.730	0.468 2.735 1.316 1.394	1.916	0.167
PPQ	41-50 51-60 61-70 71-80	0.815 1.399 1.511 2.943	0.459 0.569 1.271 0.361	1.949	0.162
sPPQ	41-50 51-60 61-70 71-80	1.101 1.645 1.817 3.973	0.403 0.616 1.046 0.967	2.563	0.096**
vF_0	41-50 51-60 61-70 71-80	2.410 3.811 4.485 6.233	1.017 1.625 2.650 1.997	3.142	0.059**

Table 3: Mean, standard deviation, F value and significance of short and long term frequency perturbation measures. * significant at a level of 0.05, ** significant at a level of 0.10

The results indicated that frequency perturbation measures increased with increase in age. Similar results were documented by Linville & Fisher (1985) and Orkiloff (1990). Indices of frequency perturbation were found to vary with advancing age (Jita, Jitt, sPPQ, vF_0) especially in the elderly male as opined by Orkiloff (1990) and Linville & Fisher (1985). Precision and control of vocal fold vibrations may be compromised in the elderly individuals which would have led to increased perturbation measures in them.

III. Short and long-term amplitude perturbation measures

Parameter	Age Group (Years)	Mean	Standard Deviation	F	Significance
ShdB	41-50	0.731	0.114	0.906	0.416
	51-60	0.740	0.653		
	61-70	0.814	0.218		
	71-80	1.507	0.407		
Shim	41-50	8.288	1.429	0.493	0.616
	51-60	8.532	0.927		
	61-70	9.027	2.625		
	71-80	12.073	4.356		
APQ	41-50	6.442	1.192	1.113	0.343
	51-60	6.504	1.066		
	61-70	7.215	1.554		
	71-80	8.560	4.133		
sAPQ	41-50	8.234	1.797	0.332	0.721
	51-60	8.560	2.015		
	61-70	9.043	2.773		
	71-80	11.243	4.701		
vAm	41-50	14.060	3.528	0.106	0.900
	51-60	14.173	3.286		
	61-70	14.823	4.991		
	71-80	20.963	7.931		

Table 4: Mean, standard deviation, F value and significance of short and long term amplitude perturbation measures.

Mean values of ShdB, Shim, APQ, sAPQ and vAm increased with aging but none were found to be significant as depicted in Table 4. It was observed that significant increases in the means of ShdB, Shim, sAPQ and vAm were seen in the age group 71 - 80 years but it was not significant. All the five acoustic parameters showed lowest mean values for subjects in 41 - 50 years and highest values for subjects in 71 - 80 years age groups.

Results also revealed that the amplitude perturbation measures were greatest for the elderly individuals. These findings are in consonance with the findings of Linville &

Fisher (1985) and Orkiloff (1990). Perturbation measures in general indicate stable and precise control of vocal folds during vibrations. Stability and precision of vocal fold vibrations were not noticed in the aged voices due to the age related changes in the vocal mechanism.

IV. Voice break related measures

Parameter	Age Group (Years)	Mean	Standard Deviation	F	Significance
DVB	41-50	0	0.341	1.414	0.261
	51-60	0.231	2.267		
	61-70	0.206	0		
	71-80	1.613	0		
NVB	41-50	0	0	2.100	0.142
	51-60	0.1	0.316		
	61-70	0.3	0.483		
	71-80	0.333	5.774		

Table 5: Mean, standard deviation, F value and significance of voice break related measures.

Table 5 shows that both means DVB and NVB revealed increased values as age advanced but none were significant. Lowest mean DVB was in subjects in 41 - 50 years age group while highest mean DVB was in 51 - 60 years age group. As for NVB, lowest mean NVB was in 41 - 50 years age group and highest NVB was in 71-80 years age group. These results indicate higher incidence of voice breaks in elderly individuals compared to younger individuals. This could be the result of reduced stability of vocal fold vibration. It could also be caused by respiratory inefficiency and anatomical changes associated with aging as documented by Hoit & Hixon (1987).

V. Sub-harmonic component related measures

From table 6, the mean values of DSH and NSH decreased with increased age but the same were not significant. The lowest mean DSH and NSH were in 71 - 80 years age group while the highest mean DSH and NSH were in 51 - 60 years age group.

Parameter	Age Group (Years)	Mean	Standard Deviation	F	Significance
DSH	41-50	0.153	0.341	1.573	0.226
	51-60	0.976	2.267		
	61-70	0	0		
	71-80	0	0		
NSH	41-50	0.3	0.675	0.715	0.498
	51-60	0.8	2.529		
	61-70	0	0		
	71-80	0	0		

Table 6: Mean, standard deviation, F value and significance of sub-harmonic component related measures.

The data suggests decreased sub-harmonic component in the voice of the aged individual. The frequency range reduced with increase of age and this in turn could reduce the incidence of sub-harmonic components in aged voice.

VI. Voice irregularity related measures

Table 7 shows mean DUV and NUV increased significantly with increase in age. DUV showed significance at a level of {$F(2, 27) = 2.64$; $p<0.10$}. Mean NUV showed significance at a level of {$F(2, 27) = 2.769$; $p<0.10$}. Duncan's post-hoc test showed that the subjects in the age range of 61 - 70 years were significantly different from other groups.

Parameter	Age Group (Years)	Mean	Standard Deviation	F	Significance
DUV	41-50 51-60 61-70 71-80	4.352 8.292 15.922 24.95	3.144 5.393 18.834 25.689	2.64	0.09**
NUV	41-50 51-60 61-70 71-80	7.2 14.5 19.1 37.67	5.371 9.058 16.71 52.00	2.769	0.081**

Table 7: Mean, standard deviation, F value and significance of voice irregularity related measures. ** significant at a level of 0.10

Increased voicelessness wasnoticed in subjects as indicated by the results. This goes in accordance with Zemlin (1968) who reported reduced ability of the vocal folds to completely adduct in elderly individuals, especially those who are in poor physiological condition caused higher incidence of voice breaks/voicelessness. Bowing of the vocal folds can be yet another possible explanation for such a finding.

VII. Noise-related measures

Table 8 shows mean NHR, mean VTI and mean SPI. It was found that mean HNR and mean VTI increased with increasing age but there were no significant group differences. The lowest mean values for all three parameters were in 41 - 50 years age group whereas the highest mean values were in the 71 - 80 years age group. The mean SPI showed significance at a level of {$F (2, 27) = 3.48$; $p<0.1$}. Duncan's post-hoc test showed significant increase in mean SPI in the age range of 61 - 70 years. Mean SPI in 51 - 60 years correlated with the other two age groups, suggesting that this parameter increased significantly for subjects in 61 - 70 years age group.

Parameter	Age Group (Years)	Mean	Standard Deviation	F	Significance
NHR	41-50 51-60 61-70 71-80	0.164 0.167 0.169 1.560	1.430 1.703 2.025 3.055	0.210	0.812
VTI	41-50 51-60 61-70 71-80	3.700 4.700 4.700 6.667	1.252 6.749 1.636 1.528	2.128	0.139
SPI	41-50 51-60 61-70 71-80	19.62 21.244 28.473 27.546	9.541 6.468 7.656 11.251	3.48	0.045**

Table 8: Mean, standard deviation, F value and significance of noise-related measures.
** significant at a level of 0.10

The results of increased NHR, VTI and SPI with advancing age find support from Ramig & Ringel (1983) who have documented increased noise component in older persons. This could be due to poor adduction of vocal folds during vocal fold vibration in the aged individuals. Increased SPI values may be an indication of incomplete or loosely adducted vocal folds during phonation as documented by the same authors.

VIII. Tremor measurements

Table 9 illustrates the values of mean FTRI and mean Fftr which showed significance at a level of {F (2,27) = 3.265; p<0.10} and {F (2,27) = 3.239; p<0.10}. Based on Duncan's post-hoc test, both mean FTRI and mean Fftr showed significant increase in the age range of 61 - 70 years. Means of FTRI and Fftr in 51 - 60 years age group correlated with both the other two age groups, suggesting that both parameters in 41 - 50 years were different, that is, increased significantly in subjects in 61 - 70 years age groups

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Parameter	Age Group (Years)	Mean	Standard Deviation	F	Significance
FTRI	41-50 51-60 61-70 71-80	0.599 0.713 1.026 2.513	0.511 0.255 0.334 0.714	3.265	0.054**
ATRI	41-50 51-60 61-70 71-80	2.687 2.783 4.652 10.017	1.612 1.201 1.715 2.511	5.191	0.090**
Fftr	41-50 51-60 61-70 71-80	5.587 2.833 4.504 8.920	3.687 0.937 1.832 1.689	3.239	0.055**
Fatr	41-50 51-60 61-70 71-80	3.994 3.622 4.516 8.467	1.417 0.894 1.306 1.612	1.357	0.275

Table 9: Mean, standard deviation, F value and significance of tremor related measures.
** significant at a level of 0.10

The lowest mean FTRI was in 41-50 years age group and highest mean FTRI was in 71 - 80 years age group. The lowest mean Fftr was in 51 - 60 years age group and highest mean Fftr was in 71 - 80 years age group. Lowest mean ATRI was in 41 - 50 years age group and highest in 71 - 80 years age range, and significance was noticed at a level of {$F (2, 27) = 5.191; p<0.10$}. Mean ATRI was significantly higher in the last age group compared to the other two groups as indicated by Duncan's post-hoc test. Mean values of Fatr also increased with advancing age, especially in the age range of 71 - 80 years, but was not significant. The lowest mean Fatr was in 51 - 60 years age group. This may be the aftermath of more irregularities in the vocal fold vibrations in old larynges which may be caused by both respiratory and laryngeal changes. Finally, tremor measurements have been considered by many researchers as the most reliable indicator of aging. The results also indicate FTRI, ATRI and Fftr measures across the age groups increased gradually. Similar findings were reported by Ryan & Burk (1974) who speculated that voice tremor as well as air loss might be voice features secondary to an increase in overall laryngeal tension.

In general, the results indicate that most of the acoustic measures changed in the third age group that is 61 – 70 years. The middle age group that is 51 – 60 years represented the transition period for changes associated with aging for most of the parameters.

B. Perceptual analysis

The perceptual analysis involved description of voices by the listeners. The results were pooled for the listeners across the age groups. The common terms that were used by the listeners were listed and pooled for estimating overall percent usage of perceptual terms. On observation, it was noticed that the judges described the voices using certain standard criteria even though they were instructed to use description. The listeners in general described voice using standard perceptual terminologies such as pitch – normal, high and low; loudness – normal, high and low; quality – normal, harsh, breathy, hoarse, rough and squeaky; and others – tremulous/shaky, denasal, glottal fry (pulse register) and resonant. Table 10 represents the percent times usage of terms indicating a specific perceived voice features as used by the listeners.

Parameter	Response	41-50 years	51-60 years	61-70 years	71-80 years
Pitch	Normal	82	84	78	77
	High	8	8	22	0
	Low	10	12	0	33
loudness	Normal	96	90	98	100
	High	4	0	0	0
	Low	0	10	2	0
Quality	Normal	58	48	30	2
	Harsh	10	14	8	27
	Breathy	6	4	6	0
	Hoarse	24	30	54	47
	Rough	2	4	2	6
	Squeaky	0	0	2	0
Others	Normal	90	96	90	60
	Strained	4	0	4	13
	Tremulous/shaky	4	2	2	13
	Denasal	0	2	2	0
	Glottal fry (pulse register)	0	0	2	2
	Resonant	2	0	0	0

Table 10: Usage of a specific term indicating specific perceived voice features (in %).

41 - 50 years: Pitch was described 82% of the times as normal, 8% of the times as high and 10% of the times as low. Loudness was perceived as adequate or normal in 96% of the times but increased loudness was reported by 4% of the times by the listeners. Quality of voice was mostly described as being normal (58%); however other terminologies were also used to describe the quality of voice such as: hoarse voice (24%), harsh voice (10%), breathy voice (6%) and rough (2 %). Most of the samples were not reported to have any significant deviations (90%); however, few of the samples were labeled as strained voice (4%), tremulous/shaky (4%) and resonant (2%).

51 - 60 years: Listeners attributed normal pitch 84% of the times. High pitch (8%) and low pitch (12%) were also reported by some of the listeners. Ninety percent of the times the listeners suggested normal or adequate loudness but 10% of the times, voice was said to be lowered in loudness. Listeners indicated quality as normal 48% of the times. Other characteristics indicated were hoarse voice (30%), harsh voice (14%), breathy voice (4%) and rough voice (4%). Other descriptive terms used were tremulous/shaky voice (2%) and denasal voice (2%).

61 - 70 years: Seventy-eight percent of times, the samples were judged as having normal or appropriate pitch. However, high pitch was reported 22% of times by the listeners. Loudness was almost uniformly judged as normal or adequate 98% of times but reduced loudness was reported 2% of times. The majority of samples were judged as being hoarse 54% of times while 30% of times were perceived as normal in quality. Other terms used to describe qualities in this age group were: harsh voice (8%), breathy voice (6%), rough voice (2%) and squeaky voice (2%). Four percent of the times it was described as strained; 2 % as tremulous/shaky; 2% as denasal and 2% as having glottal fry (pulse register).

71 - 80 years: The results for this age group have to be extrapolated with caution as the group consisted of only 3 speakers. A normal pitch was suggested 77% of times while lowered pitch was reported 33% of times. All samples were judged to be adequate in loudness. Forty-seven percent of the times, the samples were said to be hoarse in quality; 27% as harsh; 6 % as rough and only 2 % of the samples were judged as normal in quality. Thirteen percent were judged as strained; 13% as tremulous/shaky and 2% as having glottal fry (pulse register).

In general, the results of perceptual analysis indicated that pitch increase may be seen from 60 years onwards. This draws supports from the findings of Hartman (1979) who reported high pitch as one of the salient characteristics of the aged voice in males. Nonetheless, low pitch was also reported in many of the speakers across age groups and this finding goes in line with the study of Hartman & Danhauer (1976) and Ryan & Capadano (1978). No significant variation in loudness with the aging process was observed. This finding is supported by Ptacek & Sander (1966). However few speakers in the 51 - 60 years age group were perceived as having reduced loudness. Hoarseness of voice was seen across all four age groups but its frequency of occurrence increased steeply from 60 years onwards. This suggests that hoarseness does represent one of the important perceptual features of the aging voice which is supported by Hartman's (1979) study, wherein it was reported that the initial appearance of perceived hoarseness may be between 30 and 40 years for males. Gorham-Rowan & Laures-Gore (2006) stated that hoarseness increased with aging in both men and women. In the present study, breathiness was a descriptive feature used for speakers in 41- 80 years of age. Breathiness has been reported as a feature of aging voice by Ptacek & Sander (1966). Harshness was seen across age groups but was more for speakers above 70 years old. Voices of the speakers were also described as strained especially in the 71 - 80 years old group, thus supporting the findings of Ptacek & Sander (1966). Voice tremors were perceived in all the four age groups but more in individuals above 70 years and similar results were reported by Ryan & Burk (1974), who opined voice tremor as one of ten major perceptual variables of aging. Glottal fry was also noticed in this study for subjects above 60 years old. This finding was not in consonance with Hartman (1979) who reported the appearance of glottal fry in the age range of 30 - 40 years.

C. Correlation between perceptual and acoustic characteristics

Four of the common perceptual characteristics used by the majority of listeners to describe the voices were correlated with the acoustic parameters. The four selected perceptual characteristics were: high pitch, increased loudness, hoarseness and tremulous/shaky voice. The statistical procedure used was Pearson Product-Moment Correlation at a significant level of 0.05. The results were as follows: high pitch was found to be significantly correlated with F_0 ($r = 0.47$) and F_{hi} ($r = 0.55$). Increased loudness did not correlate with any of the amplitude related parameters. Hoarseness significantly correlated with Jita (0.395), Jitt (0.573), PPQ ($r = 0.372$), ShdB ($r = 0.358$). Tremulous/shaky voice significantly correlated with FTRI ($r = 0.69$) and Fftr (0.344). This finding was in contrast with Ryan & Burk (1974) and Gorham-Rowan & Laures-Gore (2006) who reported poor correlation between the perceptual and acoustic parameters.

D. Identification of age of speakers

The task required that the five listeners assign an exact age to each of the 33 subjects after listening to both their phonation and speaking samples. The results were pooled as the number of percent correct responses of each listener for all speakers in each age group. The combined percentage of correct identification of all the five listeners was also computed for each age group (as total L). A response was considered correct if the identified age matched with the actual age of the subject.

Age group (years)	L1	L2	L3	L4	L5	Total (L)
41-50	70%	70%	70%	100%	100%	82%
51-60	80%	70%	70%	50%	70%	68%
61-70	60%	40%	60%	60%	50%	54%
71-80	67%	33%	33%	33%	0	33%

Table 11: Percent correct age identification responses of listeners for all age groups.

Table 11 shows that the listeners could identify the age of the speaker accurately 82% of the times when speakers were in the age range of 41 - 50 years. It was 68% when speakers were in the age range 51 - 60 years and 54% for subjects in the age range of 61 - 70 years. Listeners as a whole (L) had over 50% correct responses for the first 3 age groups. Data about the fourth age group (71 - 80 years) cannot be extrapolated here due to inequal number of subjects. Listeners identified the age of subjects in younger age group correctly when compared to older age group, i.e., highest number of correct responses were obtained for subjects in 41 - 50 years age group and least number of correct responses for subjects in 61 - 70 years age group.

The accuracy of age identification decreased as age increased, indicating that estimating ages of older individuals is more difficult when compared to younger individuals. These results find support from Linville (2001) who states that listeners are able to estimate the age of a speaker with some degree of accuracy. It also supports the findings of Ryan & Burk (1974) that the process of aging brings about changes in the speech mechanism, which could be described by trained listeners. It can be assumed that listeners have preset templates and may use them to varying degrees depending upon individual experience listening strategies involved.

CHAPTER V

SUMMARY AND CONCLUSIONS

The current study was carried out to investigate the effect of the aging process on voice in normal adult males. The aims selected were to study the perceptual and acoustic characteristics of voice in the speakers, to investigate any possible correlation between the perceptual and acoustic characteristics and to investigate listeners' ability to identify the age of the speakers based on voice and speech characteristics.

The subjects who participated in the study consisted of male speakers and female listeners who judged the speech samples. All the participants had to meet the inclusion criteria to be selected for participation in the study. The speakers selected were categorized into 4 age groups: 41 - 50 years (10 speakers), 51 - 60 years (10 speakers), 61 - 70 years (10 speakers) and 71 - 80 years (3 speakers). Five listeners had completed a Master's degree in Speech-Language Pathology and with a minimum of 5 years of clinical experience judged the samples.

Phonation and a running speech sample were recorded for each speaker in a quiet environment. For perceptual analysis, 3 seconds phonation and thirty seconds speech sample were converted as tokens for each speaker. The study consisted of two phases: perceptual and acoustic analysis. In the perceptual analysis, the listeners judged the tokens individually. They described the voice and identified the age of all the speakers. The terminologies used by the listeners to describe the perceived features were then compiled and pooled for further analysis. The acoustic analysis involved analyzing each voice sample using twenty-nine selected parameters of Multi-Dimensional Voice Program (MDVP) and extracting 29 voice parameters. Four of the commonly described perceptual parameters described were selected for correlation analysis with the acoustic parameters: high pitch, increased loudness, hoarse voice, tremulous/shaky voice.

Results revealed that listeners were fairly accurate in identifying the age of the speaker as belonging to a specific age. However, the age identification scores declined across the age groups with maximum number of correct age identifications in the earlier age group (41 - 50 years). This implies that listeners were better able to estimate the age of a younger speaker correctly compared to an older one. The voice description task revealed that the listeners tended to describe a voice sample using the categories of pitch, loudness, quality and others (including strained, tremulous/shaky, denasal, glottal fry/pulse register, resonant). Analysis of the perceptual features suggested a) no significant change in pitch or loudness perception with aging, b) increased perception of hoarseness in later age groups and c) tremors, strained voice and glottal fry were commonly used to describe voice of elderly speakers. Acoustic analysis showed significant changes in two fundamental frequency related measurements (Flo and STD), four short and long term perturbation measurements (Jita, Jitt, sPPQ and vF0), two voice irregularity related measurements (DUV and NUV), one noise-related measurement (SPI) and three tremor measurements (FTRI, ATRI and Fftr). Significant correlation was found between high pitch and both F0 and Fhi. However, increased loudness did not correlate with any of the studied acoustic parameters. Hoarseness correlated with Jita, Jitt, PPQ and ShdB. Tremulous/shaky voice correlated with FTRI and Fftr.

Future directions: The implications for future research are numerous. Research focus should be on developing norms for normally aging males and females. A larger age range with a greater number of subjects would definitely help in the process of developing norms for such a population. Results of such a study would aid in identification of the parameters that indicate changes in voice as a function of aging.

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