A COMPARATIVE STUDY OF LAUGHTER ACOUSTICS IN COLLEGE STUDENTS WITH AND WITHOUT HEARING IMPAIRMENT

Reuben Thomas Varghese

Register Number: 10SLP024

A Dissertation Submitted in Part Fulfillment for the Degree of

Master of Science (Speech-Language Pathology)

University of Mysore

Mysore

ALL INDIA INSTITUTE OF SPEECH AND HEARING

MANASAGANGOTHRI, MYSORE – 570 006

MAY 2012

CERTIFICATE

This is to certify that this dissertation entitled **"A Comparative Study of Laughter Acoustics in College Students With And Without Hearing Impairment"** is a bonafide work submitted in part fulfilment for the degree of Master of Science (Speech- Language Pathology) of the student Registration No: 10SLP024. 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 diploma or degree.

Mysore
May, 2012

Prof. S. R. Savithri
Director
All Institute of Speech and Hearing,
Manasagangothri, Mysore- 570 006

CERTIFICATE

This is to certify that this dissertation entitled **"A Comparative Study of Laughter Acoustics in College Students With And Without Hearing Impairment"** has been prepared under my supervision and guidance. It is also certified that this dissertation has not been submitted earlier to any other university for the award of any diploma or degree.

Mysore
May, 2012

Prof. S. R. Savithri
Guide
Prof. in Speech Sciences & Director
All Institute of Speech and Hearing,
Manasagangothri, Mysore- 570 006

DECLARATION

This is to certify that this master's dissertation entitled **"A Comparative Study of Laughter Acoustics in College Students With And Without Hearing Impairment"** is the result of my own study under the guidance of Dr. S. R. Savithri, Prof. in Speech Sciences & Director, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other university for the award of any diploma or degree.

Mysore **Register No. 10SLP024**
May, 2012

ACKNOWLEDGEMENTS

First and foremost, I would like to express my deepest gratitude to my guide, Dr. S.R Savithri, Professor in Speech Sciences for her constant support, guidance and inspiration for making this study possible. In spite of the busy schedule as the director, thank you madam for always greeting me with a warm smile, patiently listening to my doubts, and giving me valuable suggestions.

I would also like to thank Mr. Sameul. N. Mathew, Director, National Institute of Speech and Hearing, Trivandrum, Kerala for permitting me to do my data collection in NISH.

I thank all the subjects who had participated whole heartedly for my study.

Geetha Mam, Shyamala Mam, Manjula Mam, Prema Mam, Sreedevi mam, Pusphavathi Mam, Goswami Sir and Venketesan Sir, for all the research inputs I had had received during class presentations.

Prof. Rangasayee, Dr. Geetha Mukundan and Mrs Usha Dalvi for their valuable advice and bleesings which I had received during my undergraduation.

Swapna Mam, for being a wonderful class mentor for two years and a constant source of encouragement for me.

JK Sir, Sudhakar Sir, Sangeetha G, Nayana Nair, for clearing my doubts whenever necessary.

I thank Vasanthalakshmi Mam and Santosh Sir for helping me with the statistical analysis.

My classmates – the smart 36 SLPs and the Gen AUD gang for the fun we had throughout the entire two years.

All my seniors and juniors for their support.

Last, but not the least, my parents, grandfather and my sister for their well wishes and prayers for the successful completion of this dissertation.

Dedicated to

Papa, Amma

& Savithri Madam

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

"Laughter is a mechanism everyone has; laughter is part of universal human vocabulary. There are thousands of languages; hundreds of thousands of dialects, but everyone speaks laughter in pretty much the same way".

Provine (2000)

Laughter is the natural reaction of humans to moments of humour or a visible manifestation of amusement. Laughter is a nonverbal mode of communication that can occur independently as well as in the context of spoken language. In human vocal communication, laughter plays a ubiquitous role being frequently produced in diverse social circumstances throughout life. Laughter has shown to occur in a wide assortment of cultures (e.g., India: Savithri, 2000; Norway: Svebak, 1975; Papua New Guinea: Eibl-Eibesfeldt, 1989; Tanzania: Rankin & Philip, 1963; United States: Bachorowski, Smoski, & Owren , 2001). Laughter has also been displayed across ages and genders (infants and children: Grammer & Eibl-Eibesfeldt, 1990; Hall & Allin, 1897; Mowrer, 1994; Nwokah, Davis, & Fogel, 1999; adults: Bachorowski et al., 2001; LaPointe, Mowrer, & Case, 1990).

The acoustic signal of laughter is idiosyncratic in nature. It comprises of a sequence of rapid, repetitive vocalic segments produced by a staccato outward breath. Each vocalic segment normally entails a fricative (aspirated ‘h’ sound) followed by a vowel component (Ruch & Ekman, 2001). Provine (2000) in particular has highlighted that laughter is a harmonically rich vowel like syllable, further arguing that even though the vowel quality can show noticeable variation among laugh bouts, it is highly consistent within a series. With a possible exception of variation in the first or last sounds of a bout, laughter is produced by the aspirated concatenation of either “ha,” “he” or “ho” sounds in distinct bouts. A typical laugh has /ha/ or /he/ and is about 75 ms duration. The time difference between two such laughter notes or calls is about 210 ms (Provine, 2000). Bickley and Hunnicut (1992) studied a small set of laughs and the results revealed that laughs could be described as array of alternating unvoiced and voiced segments. Savithri (2000) reported that average duration of a laugh syllable was 204 ms, while the average number of syllables per laugh was 4. The periodic portion of the laugh was found to be short in terms of duration and the unvoiced portion was longer. The F0 range was about 100-155 Hz for male and 161-476 Hz for female. The formant values were found to be 650 (F_1), 1700 (F_2), and 2200 (F_3). It was also observed that males used a frequency higher than that used habitually. Majority of the laughs were half voiced and melody type was falling. Neither nasality nor tenseness was observed in any laughs.

Sounds like laughter, coughs, sneezes, and other imitative sounds are close to speech due to the fact that they are produced by the same physical structure, the human vocal tract. As a consequence of not hearing their own sounds/vocalizations, persons with hearing impairment (PHI) might exhibit less opportunity to acquire experience guided control over associated respiratory functions, along with laryngeal, oral and other vocal tract musculature.

Several factors could modify the laughter of PHI relative to normally hearing persons - aspects of vocal production by PHI have been found to be different compared to hearing individuals, which mainly includes slow, monotone speech with a breathy or harsh voice quality (e.g., Leder & Spitzer, 1993; Okalidou & Harris, 1999; Osberger & McGarr, 1983). Researchers have also asserted the likelihood of impaired laryngeal and oral musculature in PHI (LaPointe et al., 1990). Such paucities could lead to the slower, elongated vowels reported for the speech in PHI (Bakkum, Plomp & Pols, 1995). Alterations in rhythm, mainly in terms of phoneme and syllable timing have also been reported in PHI (Rothman, 1976). Studies on respiratory pattern of PHI have revealed that they initiate phonation at a low level of vital capacity and produced a reduced number of syllables per breath (Forner & Hixon, 1977). The average F0 of PHI was found to be extremely high or too low (Angelocci, Kopp, & Holbrook, 1964). Furthermore, glottal waveform of PHI displayed signs of diplophonia and creaky voice (Monsen, 1978). Thus, authors conclude that PHI has difficulty adjusting the overall tension of the vocal folds and subglottal pressure.

Dissimilarities in laughter produced by PHI and normal hearing individuals could also occur as an outcome of the different response to the stimulus material used to elicit laughter. PHI using sign language as a major form of communication share a culture that can be drastically different from that of normally hearing peers, as well as aspects of humour (e.g., Paden & Humphries, 1990; Ladd, 2003). Therefore in PHI, such discrepancies in laughter acoustics could also depend on the degree of emotive feedback during the experimental elicitation of laughter. Finally, PHI report experiencing social pressure to overwhelm spontaneous vocalizations, as these can be unpleasantly loud for hearing (Leder & Spitzer, 1993).

Distinguishable laughter has also been stated in case-studies of children who were either congenitally deaf or both deaf and blind (Black, 1984; Eibl-Eibesfeldt, 1989). Provine and Emmorey (2006) have provided basic resemblances between laughter in PHI and hearing adults reporting that the former produced normal laugh sounds, and that these vocalizations occurred primarily in pauses and at phrase boundaries occurring in sign language. This result offers an equivalent to Provine's (1993) findings which states that laugher serves to punctuate rather than interrupting speech flow in normally hearing speakers.

Laughter as a vocal communicative expressive behaviour is one of the least understood and most frequently overlooked human behaviour. Interestingly, little research is done on this species-typical vocal behaviour. As PHI have access to the visual, but not the auditory component of laughter, the present study focuses on laughter acoustics in PHI. Furthermore, relatively few relevant Indian acoustic data are available from adult hearing impaired speakers who have had less opportunity to experience laugh sounds. In this context, the present study examined the acoustic features of laughter produced by college students with and without hearing impairment. Specifically, the laughter in these two groups were compared for average frequency, highest and lowest frequency, voicing, melody type, duration between successive /ha/ laughs, formant frequencies, continuity, nasality and tenseness.

Laughter is an element of human behaviour synchronized by the brain. It aids humans to clarify their intentions in social relations and gives an emotional milieu during conversation. Laughter as a communicative signal plays an important part being in a group - it indicates acceptance and optimistic relations with people in the society. Laughter is typically contagious, and the laughter of one individual can itself incite laughter from another as a positive response. The results of this study may throw light on the coordination of subsystems of speech/laughter in PHI. The results may also contribute to the literature on laughter acoustics.

CHAPTER II

REVIEW OF LITERATURE

The review will be dealt under the following:

1. Definition of laughter,

2. Laughter as an expressive - communicative social signal,

3. Mechanism of laughter,

4. Laughter acoustics in normal individuals, and

5. Laughter acoustics in Persons with Hearing Impairment (PHI).

1. Definition of laughter

The Encyclopaedia Britannica Online (2010) describes laughter as "rhythmic, vocalized, expiratory and involuntary actions". Provine (2000) reported that laughter is one of our species' most prominent and distinctive vocalizations. Savithri (2000) reported that laughter is one of the elementary forms of phonic expression that are very similar in all human beings. Laughter is a universal human behaviour and there is no reported culture where laughter is absent. Laughter is exhibited in various modalities - it is perceived visually as well as acoustically. Apte (1985) reported that laughter is present in even those born deaf and blind. Gelotology refers to the study of humour and laughter, and its emotional as well as biological effects on the human body.

Regardless of laughter being an omnipresent human behaviour (Citardi, Yanagisawa & Estill 1996), it has yet to be empirically defined (Mowrer, 1994; Ruch & Ekman, 2001). Frequently cited descriptions depict laughter as stereotyped "ha-ha" vocalizations linked with social playfulness and positive affect (Provine & Yong, 1991; Nwokah, Hsu, Davis & Fogel, 1993). However, these descriptions are challenged by various researchers indicating that laughter encompasses a cluster of sounds (Darwin, 1872; Hall & Allin, 1897; Mowrer, LaPointe, & Case, 1987; Nwokah et al., 1993; Bachorowski et al., 2001), as well as can be triggered by a wide array of positive and negative stimuli, comprising glee, humour, tickling, surprise, nervous tension, embarrassment, and threat (Ruch & Ekman, 2001).

2. Laughter as an expressive - communicative social signal

It is estimated that laughter is about 7 million years old (Niemitz, 1990). Furthermore, it is assumed that even laughter like other vocalizations such as moan, sigh, cry, groan, etc. was there even before man developed speech and served as a dynamic social communicative signal. The frequent occurrence of laughter in social interactions, also suggest that it plays a paramount role in communication (Mowrer et al., 1987; Provine & Yong, 1991; Nwokah et al., 1993; Nwokah et al., 1999). Studies have reported that laughter tends to occur in almost over 56% of infant social episodes associated with pleasure (Papousek, Papousek, & Koester, 1986). This indicates that laughter might play a pivotal role in infant-mother relationships (Nwokah et al., 1993). Furthermore, its occurrence in conversational speech advocates that laughter might also function to simplify and punctuate speech (Provine, 1993; Nwokah et al., 1999). Grammer and Eibl-Eibesfeldt (1990) postulated that in amalgamation with body position, laughter can be used to convey information about the laugher's attitude towards the listener. In contrast, the affect induction theory (Owren & Rendall, 1997) suggests that rather than the precise communication information, laughter functions to bring about a positive emotional state in the listener (Owren & Bachorowski, 2003).

3. Mechanism of laughter

Laughter is produced as a result of chopping an outward breath into a series of both short voiced and unvoiced vocalizations, that reiterate about every one fifth of a second (Provine & Yong, 1991; Bachorowski et al., 2001 ; Vettin & Todt, 2004). Laughter requires the synchronization of respiration, phonation and resonance.

Respiration

The normal respiratory cycle comprises of four phases- inspiration, inspiration pause, expiration, and finally expiration pause. However, laughter cycle begins with an initial forced exhalation, followed by a more or less continuous sequence of recurrent expirations of high frequency and low amplitude which might not be phonated at times during the laughter episode (De Troyer, Ninane, Gilmartin, Lemerre & Estenne, 1987). Inspiration preceding the laugh is not necessary as laughter is produced at a low lung volume (Bright, Hixon & Hoit, 1986). Typically, the laugh cycles start around the functional residual capacity (i.e., the lung volume after a normal expiration) and end close to the residual volume (i.e., the volume of air remaining in the lungs after maximal expiration) or occasionally even surpass the level of maximal voluntary exhalation (Lloyd, 1978; Bright et al., 1986). To summarize, during laughter episodes the initial forced exhalation expels the tidal volume and the following series of laugh pulse is based on the expiratory reserve volume. As a result the amplitude during laughter might be 2.5 times higher than during resting respiration.

The muscles that play a major role in laughter episodes include the diaphragm, ribcage muscles and the rectus abdominus (Hoit et al., 1988). The respiratory muscles work in unison with the rhythmic closing and opening of the laryngeal muscles which interrupts the airstream. This adduction prevents the air being exhaled rapidly, and allows building up and maintaining subglottal air pressure. The forced exhalation during the initial part of laugh episode also raises the transdiaphragmatic air pressure by about 5440 Pa to 6120 Pa (Schroetter, 1985). This heightened pressure plateau is maintained which later forms the basis for the sustained period of phonation of the laugh utterances.

Phonation

Laughter pulses are produced by a sequence of rapid, continuous and stereotypic laryngeal alterations. The four separate stages include interpulse pause, adduction of the arytenoid cartilages, vibration of vocal folds, and abduction of the arytenoid cartilages (Moore & Von Leden, 1958). The inter pulse pause refers to the period of silence observed between the audible instants of laughter. During this phase, the breath stream flows unrestricted through the larynx, and the vocal folds remain stationary. Certain aspirated sounds that are produced during this time become more audible as the vocal cords come in contact with each other. The production of "h" sound occurs in this phase. During the adduction stage, the arytenoid cartilage move the vocal cords towards one other and as the glottal space is narrowed, the vocal cords begin to vibrate, while in abduction the arytenoid cartilages move the vocal cords apart from each other. Laryngeal EMG studies have revealed that during laughter, the thyroarytenoid and the posterior cricothryroid are involved in the glottal adduction, whereas the abduction is achieved by the posterior cricoarytenoid muscle (Luschei, Ramig, Baker & Smith, 1997).

Resonance

The buzz sound that is produced in the glottis is transferred to the resonance tract whose shape decides the sound of laughter. Even though the respiratory and laryngeal movements during laughter pulses are mostly stereotyped, the acoustic output is variable. During courteous laughter, the schwa vowel is mostly uttered, while in emotional laughter the same may not be observed as the supralaryngeal movements might be modulated by the emotional state of the person. Citardi et al. (1996) reported that during voluntary laughter the larynx moves along the superior - inferior direction. Pitch variations in laughter depends on the lifting or lowering of larynx as well as protruding or retracting the lips. Furthermore, the length and tension of the vocal cords is also vulnerable to the emotional arousal which also determines the tension/ relaxation in the laryngeal area. Similarly, pharyngeal width or narrowness also determines the voice quality of laughter. It has been found during positive emotional states there is a widening of the throat producing a definite type of laugh, whereas in disgust there is a narrowing of the throat which matches with that of contemptuous laughter. During joyful laughter, the tongue (involved in producing high and low and front and back vowels) is likely to be in a resting central position. Habermann (1955) reported that mouth opening as well as the degree of aperture of the mouth affects laughter and nasals tend to occur likely for mild laughs.

4. Laughter acoustics in normal individuals

Laughter consists of both visual display and vocalization. The visual display has been extensively discussed in scientific literature (e.g., Darwin, 1872; Van Hooff, 1972), while the acoustics of human laughter have only more recently begun to get significant scientific attention (Bachorowski et al., 2001). Findings from relevant literature in laughter acoustics in chronological order are depicted below.

The pioneer and foremost study in laughter acoustics was done by Mowrer et al. (1987). The authors elicited laughter from 11 male college students by showing them funny video-clips. The researchers analyzed the first 5 laugh episodes produced by each participant, and made a comparison between the acoustics of laugh sounds to the acoustics of speech produced by the same individual. The findings revealed that certain acoustic characteristics were found to be distinctive of laughter. High maximum F0 was considered the strongest feature of laughter, and was reported to reach values almost twice as high as the mean F0 of speech. Large F0 range (106.5 - 450.6 Hz) was also considered a distinctive feature, with the first syllable being similar to speech, but exhibiting variation in the later syllables. The laugh duration ranged from 0.19 - 3770 ms, showed positive correlation with the number of syllables within a laughter episode (between 1 and 25). Compared to the rate of speech, which accounts to 3.84 - 3.94 syllables/s, the average laugh rate was slower which accounts to 5.55 syllables/s. Finally, Laughter episodes showed variability within and between participants in most measures. Mowrer et al. (1987) advocated that these discrepancies might reveal the extent of humour perceived by each participant by the stimulus presented to them.

Later, Provine and Yong (1991) investigated laughter acoustics in both genders. The authors elicited laughter by asking 51 participants (28 females and 23 males) to "simulate hearty laughter". The resulting data mainly consisted of "ha-ha" laughter, which the authors concluded to be the most frequent variant among laughs. They also reported that laughter consisted of almost identical laugh-notes that resembled the syllables “ha,” “he,” or “ho,” and was found to be temporally symmetrical. Hence, laughter sounded the same whether each laugh note was played either forwards or backwards. Even though, the authors termed the syllables as vowel-like, they highlighted that the vocal tract resonances involved were different than those used during normal speech. Each laugh was composed of a minimum of 4 and maximum of 16 notes, with each note lasting approximately 75 ms. Durations between laughter notes were found to be constant across participants, although durations of the first 4 notes showed variation in position for female participants in particular. It was noticed that for both the gender, inter note intervals significantly increased, while the note amplitudes decreased over the sequence of a laugh. The authors emphasize that laughter has a “sonic signature” characterized by stereotyped features, comprising of note structure, duration, and amplitude. Provine and Young (1991) further stated that although there are notions of laughter being innate, these findings suggest that laughter is a fixed behaviour.

In an attempt to probe into laughter acoustics in children, Nwokah et al. (1993) recorded laughter in four 3-year-old children during spontaneous free-play sessions with their mothers. The experimenters used a different terminology than that by Provine and Yong (1991) and described laughter in terms of syllables. Especially during heightened states of arousal, these syllables were found to last 220 ms or longer. The fundamental frequency was highly variable and ranged between 300-3000 Hz. Mean F0 ranged between 400-500 Hz which was reported to be higher than the mean F0 of infant speech (300 Hz).

Extending on Mowrer et al. (1987) study, Bachorowski et al. (2001), analyzed a total of 1024 laughter episodes making it the most comprehensive study in laughter acoustics from 97 participants (52 females and 45 males) and included all vocalizations that would be perceived as laughter by ordinary listeners. The authors reported that laughter could be either voiced and vowel like (produced though vibration of the vocal folds), or unvoiced and noisy (produced with turbulent air flow and not vocal-fold vibration). They also stated that unvoiced laughs were the most frequent type, making up 48% of the total number of laughter episodes analyzed. Fully voiced laughs, the most common variant, which was reported in earlier studies, made up only 30% of this sample. The remaining 22% were mix types of laughs. Laughs were also categorized according to the manner of production. The researchers testified laughs being produced using open- and closed-mouth positions, and on inhalation as well as exhalation. Laughs persisted for just under 1 s, and contained an average of 3.39 syllables. Bachorowski et al. (2001) described laughter in terms of “calls” rather than syllables in their study. Mean call duration was found to be about 170 ms, and laughs were produced at a rate of 4.37 calls/s, that was lower than reported by Mowrer et al. (1987), nevertheless higher than in speech. Mean F0s of voiced laughter were 405 Hz for female and 272 Hz for male participants respectively, both significantly higher than reported mean F0s of speech. Formant frequency analysis laughter indicated that it did not exhibit distinctive vowel qualities (such as “ha,” “ho,” or “he”). Bachrowski et al. (2001) elicited laughter and provided strong evidence that laughter is highly variable. However, the acoustics of spontaneous laughter may be different.

Vettin and Todt (2004) investigated spontaneous laughter occurring during discourse. Laughter was recorded tactfully from 10 individuals (6 females, 4 males) both in natural, as well as experimental contexts. The experimenters reported that casual laughter was characterized by a mean of 3 syllables, fluctuating between 1 and 21 syllables. Mean F0 was found to be 315 Hz for females and 171 Hz for males, with maximum F0 of 357 Hz and 199 Hz, respectively. Compared to laughter elicited by funny video clips, conversational laughter episodes were characterized by variable temporal and F0 characteristics. However, both the number of syllables per laugh and mean F0 in these syllables were lower in conversational laughs than in humour-simulated laughs. The researchers concluded that laughs produced under various environments may be acoustically different, which suggests that findings from any one particular analysis may not be generalizable to laughter as a whole. This conclusion supported earlier findings of acoustic specificity in laughter produced in different milieus (Milford, 1980).

Most of the studies in laughter acoustics have often produced variable results. Different operational definitions of laughter, primarily the inclusion of unvoiced as well as voiced types of laughs in the analyses, have most likely contributed to these inconsistent results. As Mowrer et al. (1987) and Nwokah et al. (1993) advocated, variations in results might also be attributed to the reaction of the individual to a particular humorous stimuli or other stimulation involved.

According to Vettin and Todt (2004) some of the discrepancies found between Provine and Yong's (1991) results and the other researchers may be due to differences in context. The laughter produced by Provine and Yong's participants may also not have been spontaneous, as they were explicitly asked to simulate laugh sounds.

Szameitat, Darwin, Szameitat and Alter (2011) investigated the fundamental frequency as well as the formant frequencies of the vowels produced in the laughter vocalizations. Eight trained actors (three males and five females) were asked to produce laughter appropriate for various emotional settings such as joy, tickle and sneering. The participants were instructed, with the help of self-induction methods, to place themselves in appropriate emotional states, and to laugh spontaneously without thinking about the expression of the laughter. Recording was done using a digital audio tape recorder in a sound-treated room, with a speaker-microphone (MP Sanyo -101 model having cardiod response) placed at a distance of 0.25 m. All recordings were digitized, normalized and segmented into individual laughter sequences. F0 in males was 199 Hz, while in females was 476 Hz. The results revealed that vocalic segments showed higher average F_1 than those reported in previous, individual values, which were as high as 1100 Hz for male and 1500 Hz for female speakers respectively. The authors conclude that these exceptionally high F_1 values are likely to be based on the extreme positions adopted by the vocal tract during laughter, along with physiological constraints associated with the production of tensed voice.

Savithri (2000) investigated the acoustic features of laughter in one hundred normal speakers (35 males and 65 females) between the age range of 18 to 46 years. The laughs were elicited either by using Kushwant Singh’s jokes or a laughing sample was played. The laughs were audio- recorded on to a cassette, which was then recorded into the memory of the computer at a sampling frequency of 12000 Hz using the CSL external module. Using CSL version 5.05, the pitch was extracted and spectrograms with 75 Hz bandwidths were obtained. The various measures performed were average frequency, lowest and highest frequency, habitual frequency, voicing, melody type, duration between successive /ha/ laughs, continuity, glottal plosive, nasality and tenseness. Results indicated that the average frequency of laugh was 199 for males and 219 Hz for females. While males used frequencies higher than their habitual frequencies in phonation, females had the same frequencies in laugh and phonation. Females had a higher frequency range than males though not significantly. It was also found that the percent of almost voiced/unvoiced was negligible. It appeared that the percent of half -voiced was more than that of voiced or unvoiced. The melody type was most of the time falling (63%) followed by rise fall and least appearing melody type was flat or fall-rise-fall. The duration between /ha/ of the laugh was about 85 ms in males and 157 ms in females indicating a longer inter laugh duration in females. The formant frequencies appeared to coincide with /a/ in both males and females. The laughs were continuous. In some individuals, glottal plosives were present (20%). No nasality and tenseness were observed in any laughs. The author reported that males having a higher frequency in laugh compared to that in phonation may be due to the higher laryngeal positioning during laugh compared to phonation. The wide range of frequencies used indicated maximum rising and lowering of the larynx. The source characteristics changed with type of laugh. While for voiced laugh the vocal folds were vibrating, for the unvoiced, they were apart, and vibrating/ wide apart for half voiced. Majority of the melody type being falling indicated fall of F0 in the sentence end of laughter.

Jacob, Chandrasekra & Kumar (2011) investigated the formant frequencies of laughter in children. Nineteen normal children in the age range of 3-7 years participated in the study. All participants were devoid of speech, language and neurological problems. They were seated comfortably in recording room of the speech science laboratory and were tested individually. Laughs were elicited through play and tickling the children. The entire interactions were audio recorded onto Praat software (version 5.0.11) at a sampling frequency of 44.1 KHz. Using the same software, only laughs were extracted and wide band spectrograms were obtained for the vocalic portions of laughter. The laughter sequences that contained words, interjections were excluded. The background noise, laughter of short duration (<3 sec) or low amplitude (with non-detectable pitch) were also rejected. The parameters analyzed included the number of bouts in laughter and the first two formant frequencies. The results revealed that the mean bout of the laughter was 3. The average first and second formant frequencies were found to be 711.44 Hz and 2036.94 Hz, respectively in children. The authors report that number of bouts was less in children due to the reduced vital capacity. The increased formant frequencies in general were supported by the fact that children have a smaller vocal cavity in comparison to that of adults (Rendell, Kollias, Lloyd & Ney, 2005). Average first formant frequency was similar to that of vowel /a/ spoken by adults which is in consonance with the previous study done by Savithri (2000) wherein it is reported that F1 of laugh syllable was similar to that of /a/ spoken by an adult. In contrast, Szameitat et al. (2010) study reported that F1 was high in both males and females due to the changes of the vocal tract. Average second formant frequency was extremely high than that of /a/ spoken by adults. This supports the viewpoint of laughter specific vowel proposed by Pearce (2004). The authors attributed the different results on formant frequencies due to the fact that laughter may be culture determined (Kovi, 1987).

5. Laughter Acoustics in Persons with hearing impairment (PHI)

Provine and Emmorey (2006) investigated laughter amongst deaf signers. Thirty eight participants (19 men and 19 women) between the age range of 15 to 60 years (Mean 41 years) took part in the study. Out of the thirty eight participants, twenty-four were native signers i.e. born into deaf signing families, and 14 acquired ASL later in childhood. The data comprised of 125 digitized laughter episodes extracted from 11 videotaped, casual, signed conversations between two to five participants. Of the 11 conversations, two included only male participants, one included female participants, and eight included both male and female participants. The videotapes, each about 30 minutes in duration, were recorded as a part of a sociolinguistic study of ASL signers (Lucas, Bayley & Valli, 2001). The analysis included only instances were laughter was clearly vocalized; visual signs of laughter such as smiling, shaking shoulder movements etc. that were not accompanied by audible vocal patterns were excluded from the analysis. Results revealed that laughter occurred 2.7 times more frequently during pauses and at phrase boundaries than simultaneously with a signed utterance. Thus the authors conclude that the laughter involves higher order cognitive or linguistic processes rather than the low level regulation of motor processes competing for a single vocal channel.

Makagon, Funayama and Owren (2008) compared the acoustic properties of laughter in 19 congenitally, bilaterally profound deaf college students (12 females and 6 males) and in 23 normally hearing control participants. Laughter was elicited by viewing funny comedy clips. The severely deaf participants neither used hearing aids nor other auditory facilitation. Laughter was recorded using Special Project head worn microphone. Acoustic analysis was initially done using PRAAT software (Boersma, 2009) and later analysed using ESPS (Entropic Research Laboratory). The researchers reported some differences between the laughter of deaf and hearing groups; the most significant being that the deaf participants produced lower amplitude and longer duration laughs. The number of laughter bouts from deaf participants was significantly less compared to the laughter bouts from hearing participants. This difference was also observed in separate analysis of unvoiced bouts, but not mixed bouts. No significant difference was noticed in bout duration by gender. Burst level outcomes revealed that deaf laughers produced a significantly higher percentage of unvoiced bursts than hearing laughers. The mean relative amplitude of bursts produced by deaf participants was significantly lower compared to their hearing peers. In deaf laughter, 41.2% of the laugh bursts were produced with open- mouth bursts, 64.4% closed mouth bursts, 2.5% mixed mouth bursts, and 8% were unidentifiable. The mean F0 values were also significantly lower in laughter produced by deaf compared to normal hearing participants. While there was no difference in the mean F0 between deaf males and hearing males, values of deaf females were significantly below those of hearing females. The authors report that these discrepancies are likely due to the combination of the physiological and social factors that usually affect profoundly deaf individuals including low overall rates of vocal fold vibration and social pressure to suppress spontaneous vocalizations.

Reuben and Savithri (2012) investigated the acoustic features of laughter produced by five adults (both males & females) with hearing impairment and compared it with those of normal hearing individuals in terms of average frequency, highest and lowest frequency, and voicing using funny movie clips. The results of the study revealed that there is considerable decrease in the mean, maximum and minimum

F0 in adult PHI compared to normal hearing individuals. Also more percent of unvoiced laughs were observed in PHI. The authors report that the mean F0, minimum F0, and maximum F0 values were significantly lower in laughter produced by PHI in both genders, perhaps reflecting the fact that vocal production rates are slower in PHI compared to normal hearing individuals. Normal individuals produced higher percent of half voiced laughs while PHI produced unvoiced laughs also. This difference may be attributed to the deficiencies in laryngeal and oral motor control and relatively low rates of vocalization occurring in profoundly HI individuals. The other reason could be that PHI may have been actively inhibiting their vocal responses. In addition to not being able to monitor the quality of their utterance and vocalization, PHI may also be concerned about vocalizing too loudly and feels social pressure to avoid doing so.

Reuben and Savithri (2012) in an another study extracted the formant frequencies (F_1, F_2) of laughter produced by Children with Hearing Impairment (CHI) and compared it with normal hearing children. Laughter of fifteen male CHI in the age range of 5-12 years were elicited using funny movie clips and compared with age and gender matched normal peers. The laughs were stored separately for each speaker onto a computer memory and frequency of the first two formants at the midpoint of the laughter was extracted using PRAAT -5114 software (Boersma & Weenick, 2009). The results revealed that CHI showed a slightly reduced F_1 though statistically not significant and statistically higher F_2 compared to normal hearing children. Thus authors report that the above results indicate that CHI used a relatively more neutral and less distinctive tongue configuration compared to normal peers.

The above review indicates that research in the area of acoustics of laughter in PHI is inadequate and the acoustic features of laughter produced by PHI needs to be examined further. In this context, the present study examined the acoustic features of laughter produced by college students with hearing impairment and compared it with those of normal hearing individuals. The present study extended previous laughter acoustics research by comparing acoustic features of laughter in terms of 10 parameters - average frequency, highest and lowest frequency, voicing, melody type, duration between successive /ha/ laughs, formant frequencies, continuity, tenseness and nasality as it emerges in the absence versus presence of auditory experience. Laughter produced by thirty bilaterally, and profoundly SNHL college students (15 males & 15 females) who were using hearing aid since the age of four years were acoustically analyzed and compared with age and gender matched normally hearing peers elicited in the same context. If socially proscribed long-term development affects the behaviour, laughter produced by the PHI (who had minimal experience with sound especially during initial years) should be significantly different than laughter produced by hearing participants (who had a lifetime of experience with laughter sounds).

CHAPTER III

METHOD

Participants

Two groups of subjects participated in the study. Group I consisted of fifteen male and fifteen female college students with HI in the age range of 18-26 years. The following was the inclusion criteria.

Subjects in group I had congenital bilateral severe/profound sensory-neural hearing loss; they had no structural or neurological problems, had good or corrected-to-good vision, and the absence of any respiratory ailments. All were hearing aid users (Behind the Ear- digital) since four years of age and were still continuing to use hearing aids and had attended speech therapy for a minimum of 5 years. The subjects in group I were BFA (Bachelor of Fine Arts-HI) and Bachelor of Computer Application (BCA-HI) college students.

Subjects in group II were age and gender matched to subjects in group I and they had normal speech, language and hearing (informal assessment). Subjects in group II were undergraduate and postgraduate college students undergoing speech and hearing course. Subjects in both groups were native Malayalam speakers.

Stimuli

Ten short movie clips compiled on a Digital Video disk (DVD) was used as stimuli. Five funny movie clips from comedy movies (Mr. Bean) / funny TV serials (just for laughs)/ cartoons (Tom & Jerry) were used. The rest five were taken from dramas or science fantasy films and were emotion inducing but not humorous. The latter was included in the DVD to make the cover story as plausible as possible; thereby helping to ensure that any laugh sounds produced would be impulsive and natural. In order to appeal to both PHI and normal college students, the clips were emphasized on physically based actions with minimum reliance on dialog.

Procedure

Participants were seated in a noise free recording room and oriented towards a 15.6 inches high definition Toshiba Satellite L- 650 laptop. Participants were instructed that the only task will be to sit back, repose and watch a series of movie clips. Participant's vocalizations was audio-recorded using Zebronics head worn microphone, with the microphone arm parallel to the cheek, and the tip positioned 1 inch from the left corner of the mouth.

Acoustic Analysis

Ensuing Bachorowski et al. (2001) study, laughter is defined relatively inclusive as being any perceptual vocalization that any normal person would categorize as laugh sounds. Speech sounds interfering with laughter was excluded as it would alter the acoustic properties of laughter (Nwokah et al., 1999). Each laughter event was categorized at the bout and burst levels according to spectrographic representations. A bout was defined as one entire laughter event, and a burst as a distinct sound (note, syllable, or call) occurring within that event. Grammer and Eibl-Eibesfeldt (1990) also categorized laughs in terms of voiced and unvoiced. The voiced laughter refers to vowel like sounds produced through regular synchronized vocal fold vibration in the larynx, the latter in contrast refers to noisy sounds in which the vocal folds either do not vibrate or vibrate in an uncoordinated fashion. The laughs were stored separately for each speaker onto a computer memory at mono channel, 16 bit resolution and 44

KHz sampling rate using PRAAT - 5114 software (Boersma & Weenick, 2009). The laughs were depicted as pitch contour and wide band bar type spectrograms. Figure 1 shows a sample of pitch and spectrogram for a laugh.

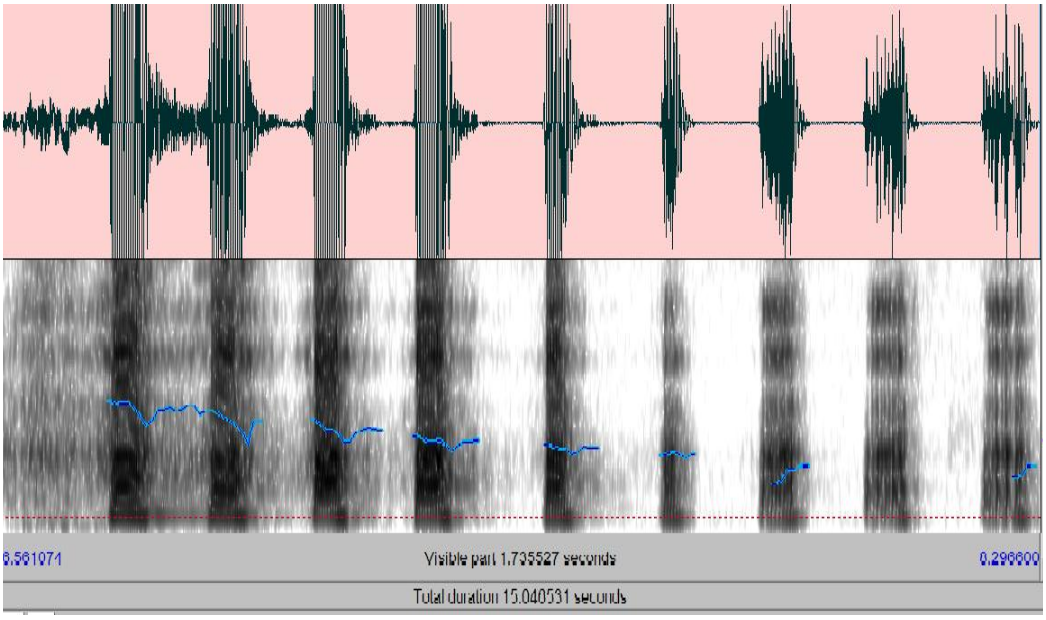

Figure 1: Waveform, F0 contour and Spectrogram for a laugh.

The various acoustic measures that were performed were as follows:

Average Frequency: This refers to the average of all the frequencies extracted in a laugh.

Lowest and Highest Frequency: These refer to the lowest and highest of frequencies in each laugh.

Voicing: This refers to whether the laugh is completely voiced, completely unvoiced or half voiced.

Melody type: Under melody type, rising, falling, rise-fall, fall-rise, rise-fall-rise, fall-rise-fall and flat will be considered as follows.

Falling: F0 decreased from beginning till end.

Rising: F0 increased from beginning till end.

Rise- Fall: F0 increased initially followed by F0 decrease.

Fall- rise: F0 decreased initially followed by F0 increase.

Rise- fall- rise: Increase in F0 followed by decrease and increase in F0.

Fall- rise-fall: Decrease in F0 followed by increase and decrease in F0.

Flat: No change in F0 over time.

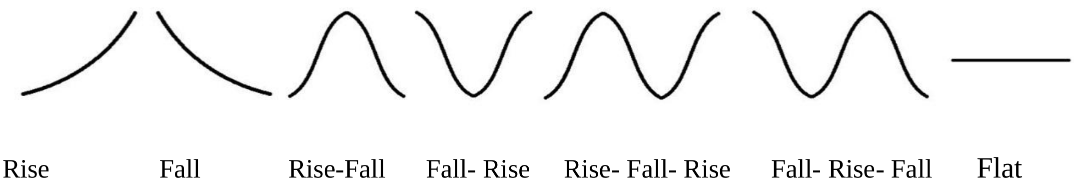

Figure 2: Melody types.

Duration between successive /ha/ laughs: This was measured as the time difference between the offset of the periodic/ aperiodic waveform and the onset of the same for the following outburst of laughter.

Formant Frequencies: The first three formant frequencies were measured from the wide band bar type spectrograms.

Tenseness (tense/lax) as indicated by high pitch was noted.

Continuity (continuous/ interrupted), and **Nasality** (present /absent) as indicated by damped formants was noted.

Statistical analysis

Commercially available SPSS (Version 16) software was used. Two - way MANOVA was performed to find the main effect of groups and gender and group * gender interaction.

CHAPTER IV

RESULTS

The aim of this study was to investigate the acoustic features of laughter produced by college students with and without hearing impairment. Acoustic parameters of average frequency, highest and lowest frequency, voicing, melody type, duration between successive /ha/ laughs, formant frequencies, tenseness, continuity and nasality were extracted and compared between groups and genders. A total of 120 laugh bouts produced by normal hearing adults and 88 laugh bouts produced by PHI were analyzed. The findings of the study will be broadly presented under following headings.

1. Average Frequency

The average F0 in normal individuals (both gender) was 260 Hz while that in PHI (both gender) was 228 Hz. The average F0 in normal males was 203 Hz while that in HI males was 148 Hz. The average F0 in normal females was 318 Hz while that in HI females was 260 Hz. Two – way MANOVA showed significant main effect of group [$F(1,28) = 4558.82$, $p < 0.001$] , significant main effect of gender [$F(1,13) = 18706.25$, $p < 0.001$] and significant group x gender interaction for average F0 [$F(1, 56) = 5.657$, $p < 0.05$]. Table 1 and figure 3 show the average F0 and SD in both groups.

	Males	Females	Combined
Group I	148 (4.87)	260 (2.02)	228 (51.74)
Group II	203 (3.92)	318 (4.06)	260 (58.50)

Table 1: Average F0 (Hz) and SD (in parenthesis) of laughter in both groups.

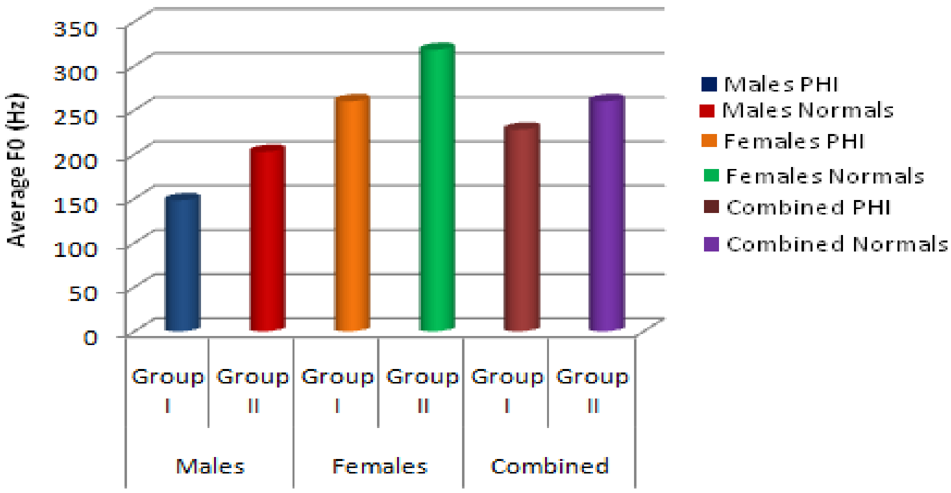

Figure 3: Bar graph depicting average F0 (Hz) of laughter in both groups.

2. Maximum F0

The maximum F0 in normal individuals (both gender) was 328 Hz while that in PHI (both gender) was 269 Hz. The maximum F0 in normal males was 301 Hz while that in HI males was 243 Hz. The maximum F0 in normal females was 355 Hz while that in HI females was 295 Hz. Two – way MANOVA showed significant main effect of group [$F(1,28) = 5560.984$, $p < 0.001$] , significant main effect of gender [$F(1,13) = 4575.39$, $p < 0.001$] for maximum F0. However, group x gender interaction was not statistically significant for maximum F0 [$F(1, 56) = 17.974$, $p > 0.05$]. Table 2 and figure 4 shows the maximum F0 and SD in both the groups.

	Males	**Females**	**Combined**
Group I	243 (3.18)	295 (4.03)	269 (26.67)
Group II	301 (2.50)	355 (2.07)	328 (27.64)

Table 2: Maximum F0 (Hz) and SD (in parenthesis) of laughter in both groups.

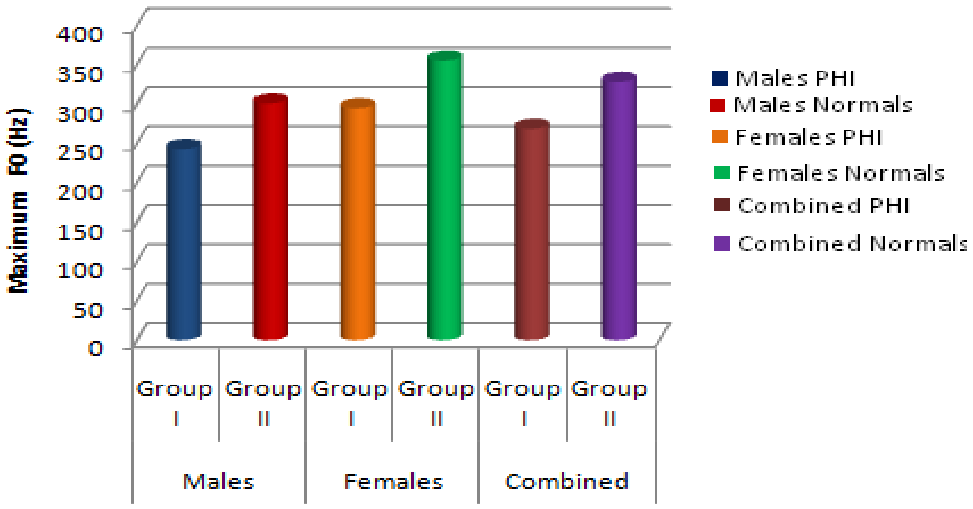

Figure 4: Bar graph depicting maximum F0 (Hz) of laughter in both groups.

3. Minimum F0

Minimum F0 in normal individuals (both gender) was 170 Hz while that in PHI (both gender) was 143 Hz. Minimum F0 in normal males was 127 Hz while that in HI males was 101 Hz. The minimum F0 in normal females was 213 Hz while that in HI females was 185 Hz. Two – way MANOVA showed significant main effect of group [F (1,28) = 2039.00 , p< 0.001] , significant main effect of gender [F (1,13) = 19777.02, p< 0.001] and significant group x gender interaction for minimum F0 [F (1, 56) = 4.951, p< 0.05]. Table 3 and figure 5 show the minimum F0 and SD in both the groups.

	Males	**Females**	**Combined**
Group I	101 (1.18)	185 (3.41)	143 (42.68)
Group II	127 (2.31)	213 (1.89)	170 (44.02)

Table 3: Minimum F0 (Hz) and SD (in parenthesis) of laughter in both groups.

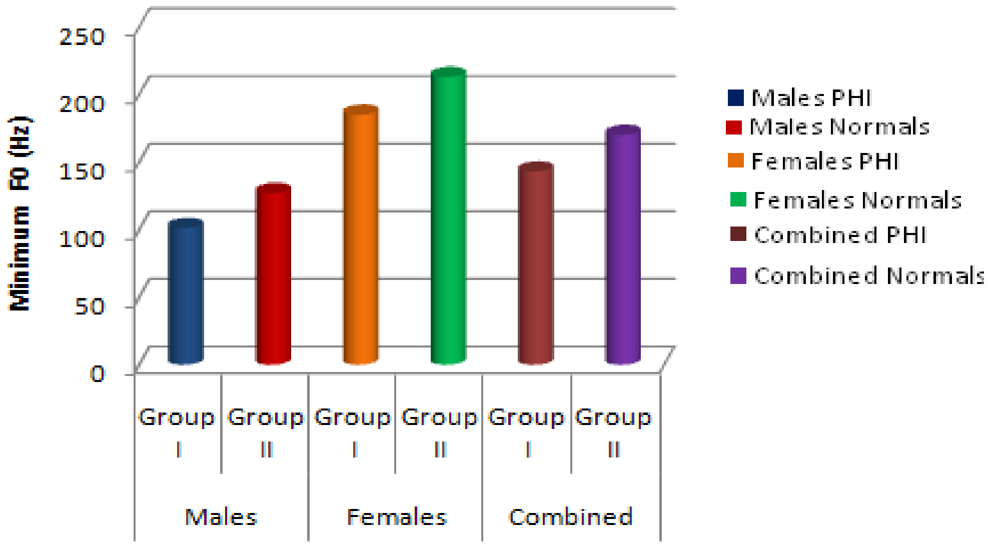

Figure 5: Bar graph depicting minimum F0 (Hz) of laughter in both groups.

4. Voicing

Majority of laughs produced by normal individuals were half voiced (Males - 95%, Females - 93%) while the amount of unvoiced laughs were less (Males - 5% and females- 7%). On the contrary, even though the majority of laughs in PHI were half voiced, they exhibited more percentage of unvoiced laughs (Males- 28 %, Females- 34%) compared to their normal peers. No fully voiced laughs were seen in any group. Table 4 and figures 6 -9 shows percentage voicing in both groups.

	Males			**Females**		
	V	**U**	**HV**	**V**	**U**	**HV**
Group I	0	28	72	0	34	66
Group II	0	5	95	0	7	93

Table 4: Percent voicing in laugh in both groups (V = Voiced, U = Unvoiced, HV= Half-voiced).

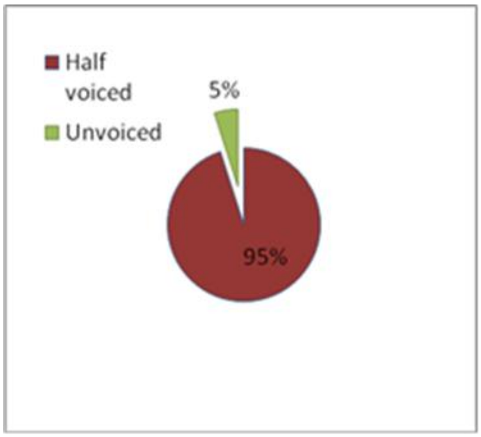

Figure 6: Pie chart showing percent voicing in normal males.

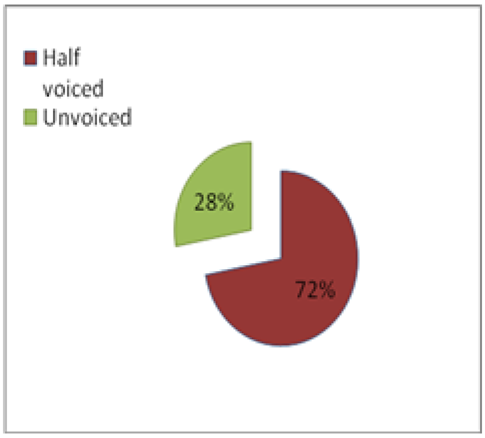

Figure 7: Pie chart showing percent voicing in HI males.

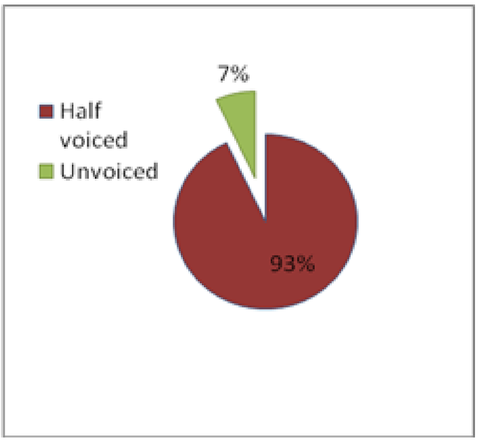

Figure 8: Pie chart showing percent voicing in normal females.

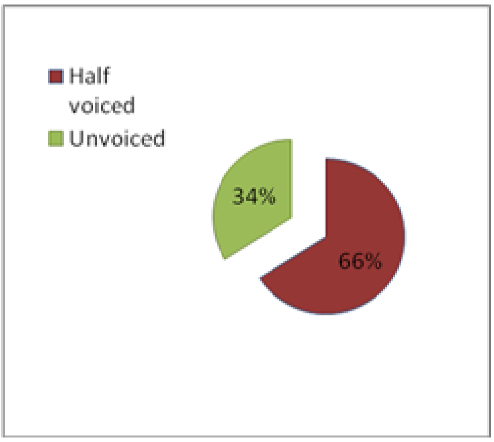

Figure 9: Pie chart showing percent voicing in HI females.

5. Melody types

Majority of the melody patterns in laughter were falling type in both the groups. The falling type pattern was slightly reduced in PHI (Males - 55%, Females -56%) compared to the normal group (Males – 62%, Females - 60%). Some PHI (both gender) produced flat melody patterns (Males- 15%, Females- 11%). However, this type of melody pattern was not found in the normal individuals. Table 5 and figures 8-11 shows the percentage of melody types in both groups.

Melody types %	Males		Females	
	Group I	Group II	Group I	Group II
Rising	17	15	16	20
Falling	55	62	56	60
Rise- Fall	10	17	12	13
Fall- Rise	3	5	5	5
Rise- Fall- Rise	0	1	0	2
Fall- Rise- Fall	0	0	0	0
Flat	15	0	11	0

Table 5: Percent melody type in laugh of both groups.

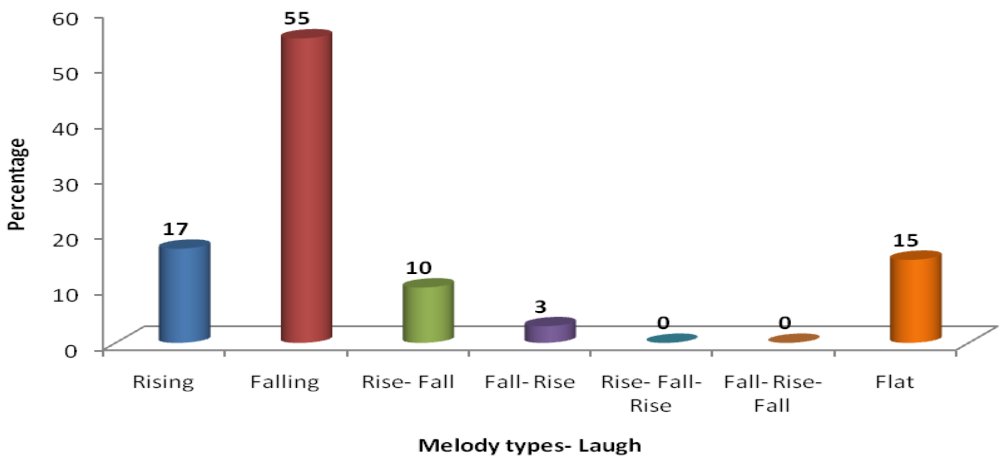

Figure 10: Bar graph depicting percent melody type of laughs in Group I males.

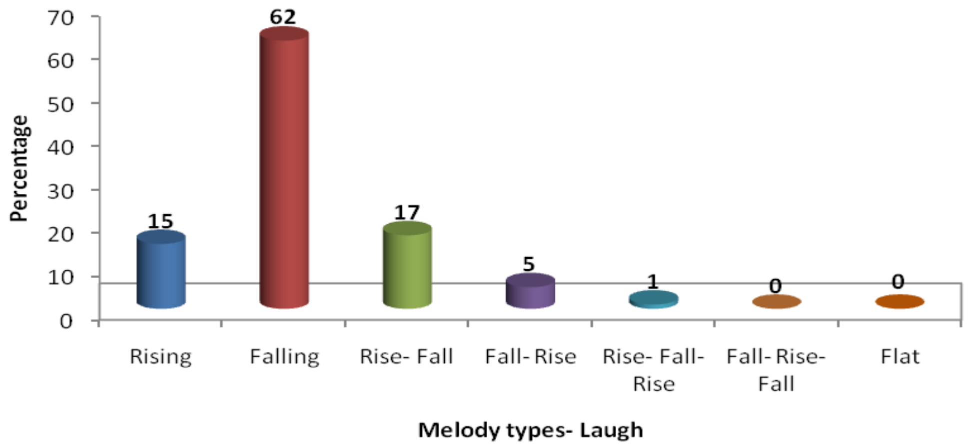

Figure 11: Bar graph depicting percent melody type of laughs in Group II males.

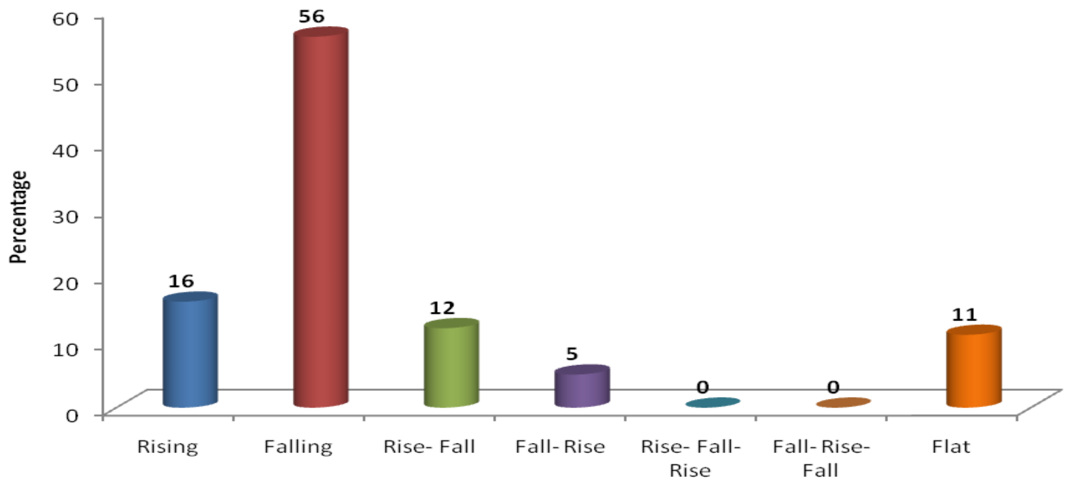

Figure 12: Bar graph depicting percent melody type of laughs in Group I females.

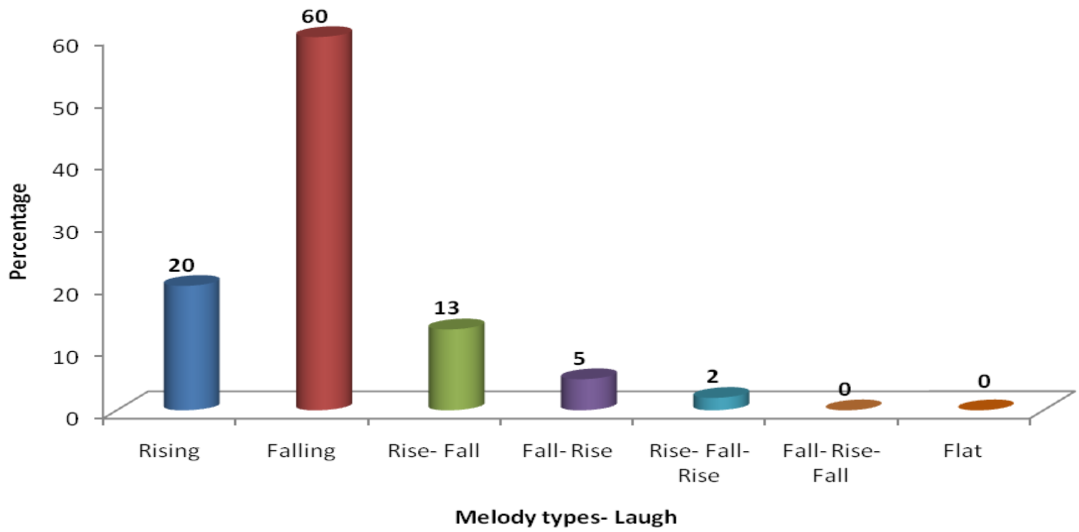

Figure 13: Bar graph depicting percent melody type of laughs in Group II females.

6. Duration between successive laughs

The results of two - way MANOVA indicated significantly longer duration between successive laughs in PHI compared to normal adults. The average duration between successive laughs in normal individuals (both gender) was 121 ms while that in PHI (both gender) was 164 ms. The average duration in normal males was

87 ms, while that in HI males was 127 ms. The average duration in normal females was 156 ms while that of HI females was 200 ms. Two – way MANOVA showed significant main effect of group [$F(1,28) = 2146.26$, $p< 0.001$] , significant main effect of gender [$F(1,13) = 5945.82$, $p< 0.001$] and significant group x gender interaction for duration between successive laughs [$F(1, 56) = 4.951$, $p< 0.05$]. Table 6 and figure 12 shows the average duration between successive laughs in both groups.

	Males	**Females**	**Combined**
Group I	127 (3.92)	200 (3.36)	164 (51.74)
Group II	87 (3.50)	156 (3.44)	121 (58.50)

Table 6: Average Successive Duration (ms) and SD (in parenthesis) of laughter in both groups.

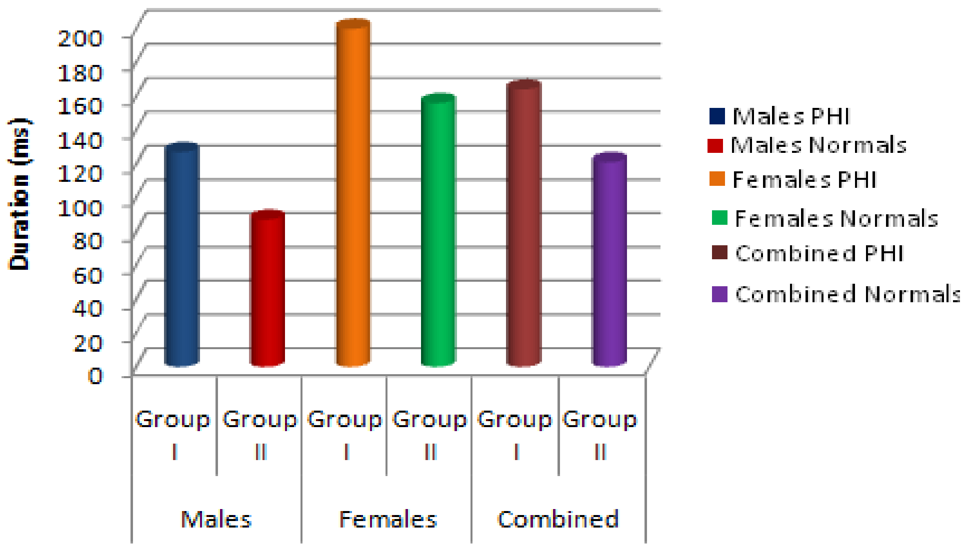

Figure 14: Bar graph depicting average successive duration (ms) of laughter in both groups.

5. Formant Frequencies

F_1: The results of two- way MANOVA indicated significantly lower F_1 in PHI compared to normal adults. The average F_1 of laugh in normal individuals (both gender) was 782 Hz, while that of PHI (both gender) was 697 Hz. The average F_1 in normal males was 773. Hz, while that in HI males was 694 Hz. The average F_1 in normal females was 793 Hz, while that in HI females was 700 Hz. Two – way MANOVA showed significant main effect of group [$F (1,28) = 3888.37$, $p< 0.001$] , significant main effect of gender [$F (1,13) = 93.04$, $p< 0.001$] and significant group x gender interaction for duration between successive laughs [$F (1, 56) = 25.33$, $p< 0.05$].

F_2: The results of two- way MANOVA indicated significantly higher F_2 in PHI compared to normal adults. The average F_2 of laugh in normal individuals (both gender) was 1465 Hz while that in PHI (both gender) was 1516 Hz. The average F_2 in normal males was 1441 Hz, while that in HI males was 1497 Hz. The average F_2 in normal females was 1489 Hz while that of HI females was 1535 Hz. Two – way MANOVA showed significant main effect of group [$F (1,28) = 334.08$, $p< 0.001$] , significant main effect of gender [$F (1,13) = 234.57$, $p< 0.001$], however significant group x gender interaction was not present [$F (1, 56) = 3.508$, $p> 0.05$].

F_3: The results of two- way MANOVA indicated significantly lower F_3 in PHI compared to normal adults. The average F_3 of laugh in normal individuals (both gender) was 2311 Hz while that in PHI (both gender) was 2193 Hz. The average F_3 in normal males was 2256 Hz, while that of HI males was 2162 Hz. The average F_3 in normal females was 2366 Hz while that in HI females was 2224 Hz. Two – way MANOVA showed significant main effect of group [$F (1,28) = 563.50$, $p< 0.001$] , significant main effect of gender [$F (1,13) = 302.58$, $p< 0.001$] and significant group x gender interaction [$F (1, 56) = 23.71$, $p < 0.05$] for F_3. Table 7 and figures 13 to 15 show the mean F_1, F_2 and F_3 in all groups.

	Males			**Females**			**Combined**		
	F_1	**F_2**	**F_3**	**F_1**	**F_2**	**F_3**	**F_1**	**F_2**	**F_3**
Group I	694 (5.02)	1497 (5.12)	2162 (14.68)	700 (4.31)	1535 (9.63)	2224 (31.95)	697 (5.61)	1516 (5.45)	2193 (40.04)
Group II	773 (6.29)	1441 (6.29)	2256 (8.49)	793 (5.61)	1489 (4.67)	2366 (13.38)	782 (11.90)	1465 (12.54)	2311 (57.45)

Table 7: Mean F_1, F_2 and F_3 (Hz) and SD (in parenthesis) of laughter in both groups.

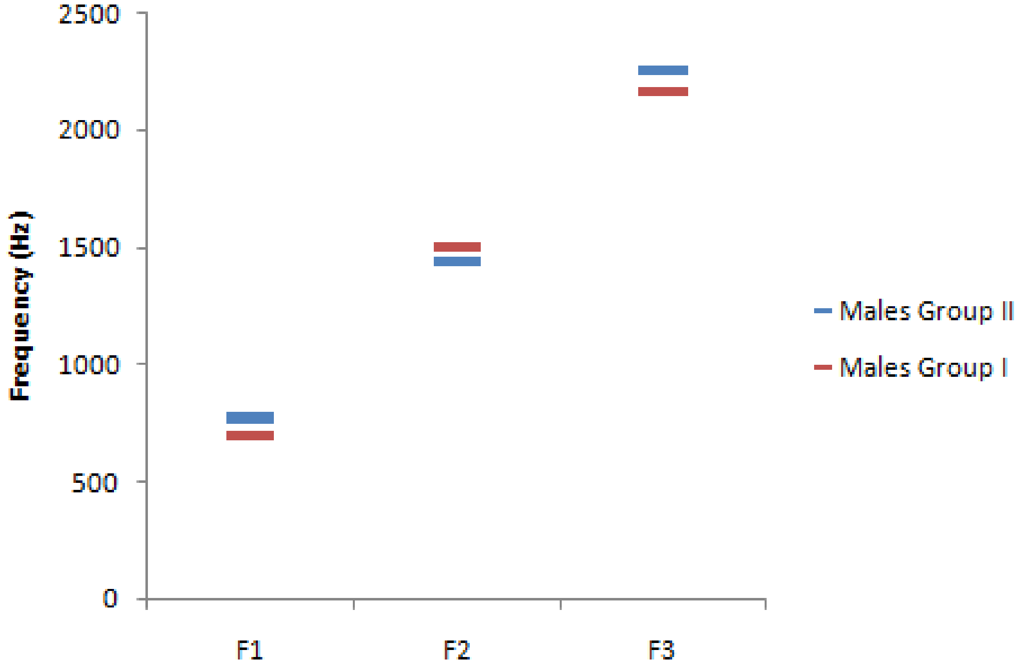

Figure 15: Line graph depicting mean F_1, F_2 and F_3 of laughter in both groups (males).

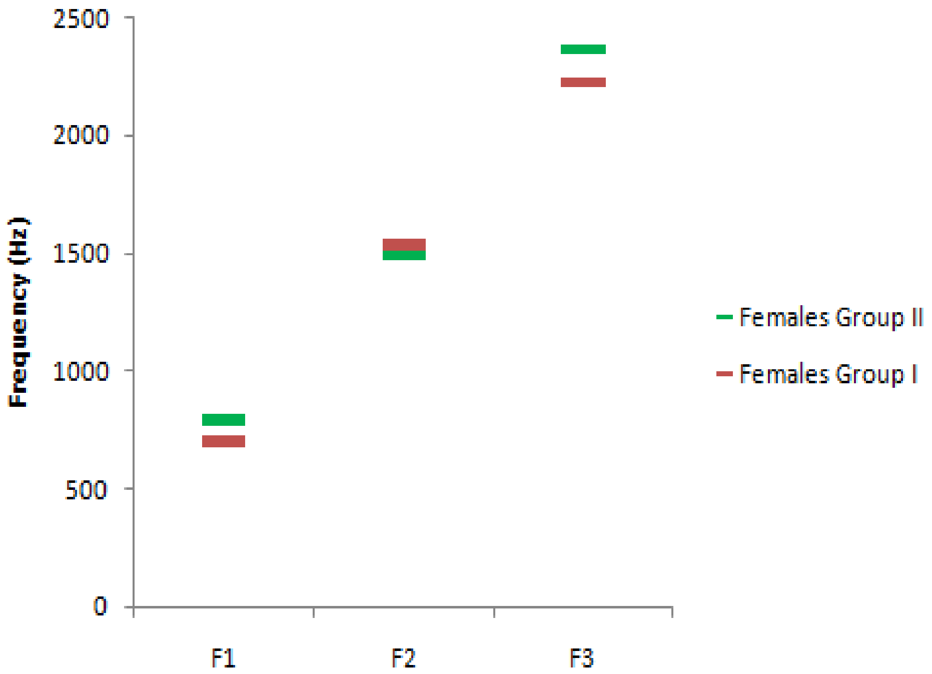

Figure 16: Line graph depicting mean F_1, F_2 and F_3 of laughter in both groups (females).

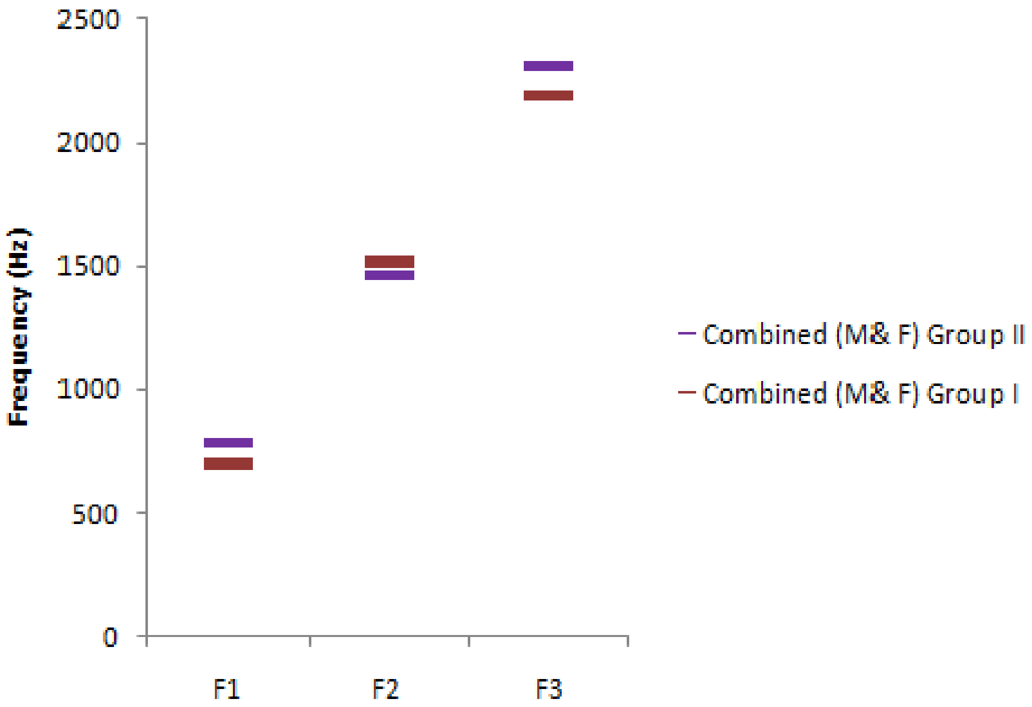

Figure 17: Line graph depicting mean F_1, F_2 and F_3 of laughter (both gender) in both groups.

8. Continuity

Majority of laughs produced by normal individuals were continuous (Males - 92%, Females – 95%). On the contrary the majority of laughs in PHI were interrupted (Males - 56 %, Females - 64%) compared to their normal peers. Table 8 and figures 16- 19 shows percent continuity in laughs in both groups.

	Males		Females	
	C	I	C	I
Group I	44	56	36	64
Group II	92	8	95	5

Table 8: Percent continuity in laughs in both groups (C = Continuous, I =Interrupted).

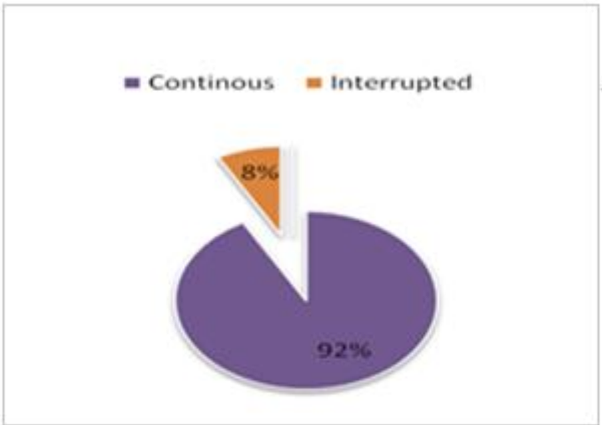

Figure 18: Pie chart showing percent continuity of laugh in normal males.

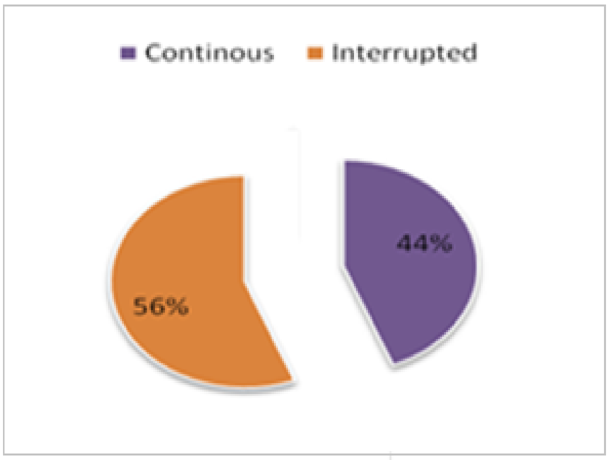

Figure 19: Pie chart showing percent continuity of laugh in HI males.

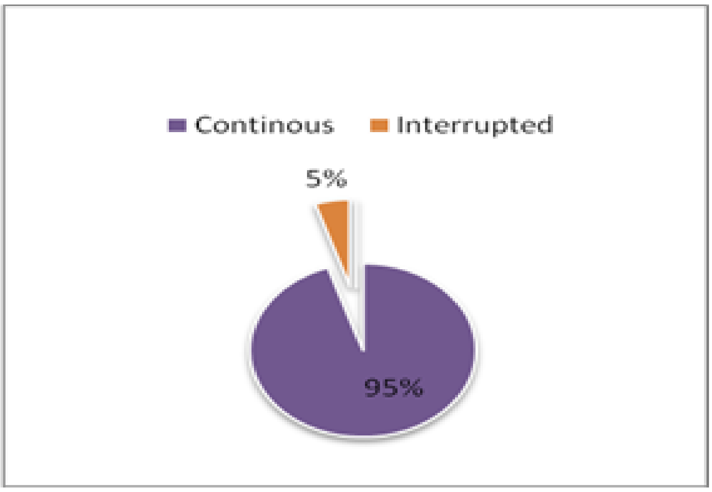

Figure 20: Pie chart showing percent continuity of laugh in normal females.

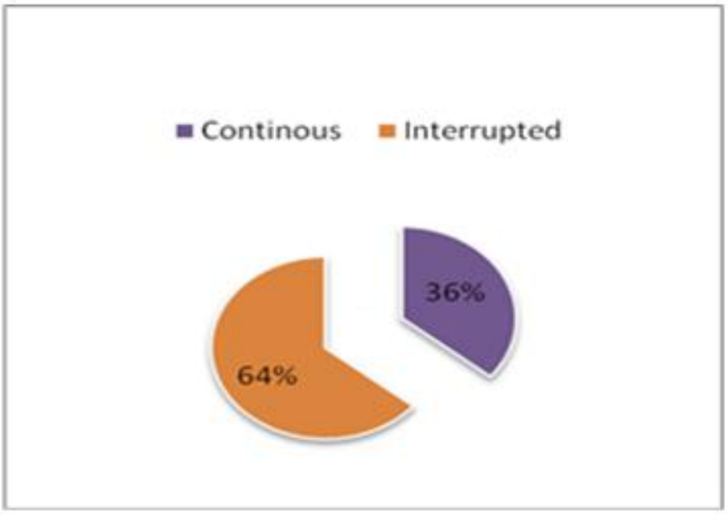

Figure 21: Pie chart showing percent continuity of laugh in HI females.

9. Tenseness

Majority of laughs produced by normal individuals were lax (Males -88%, Females – 86%). On the contrary, majority of laughs in PHI were tense (Males- 54 %, Females- 56%) compared to their normal peers. Table 9 and figures 20-23 shows percent tense/lax in laugh in both groups.

	Males		Females	
	T	**L**	**T**	**L**
Group I	54	46	56	44
Group II	12	88	14	86

Table 9: Percent tense/lax of laughs in both groups (T = Tense, L = Lax).

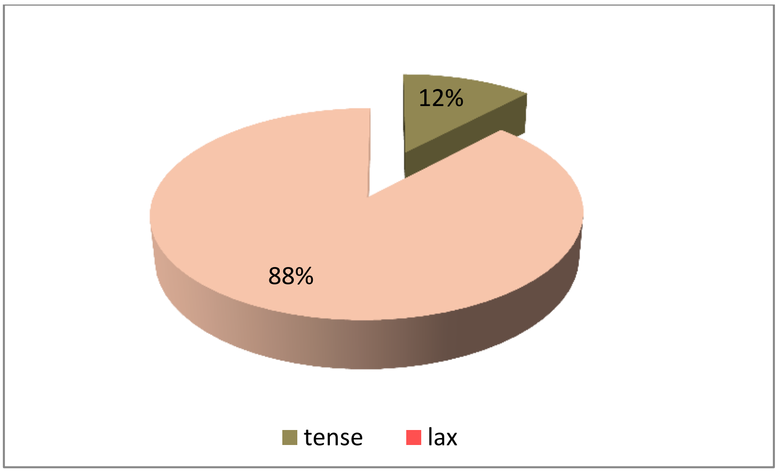

Figure 22: Pie chart showing percent tenseness of laugh in normal males.

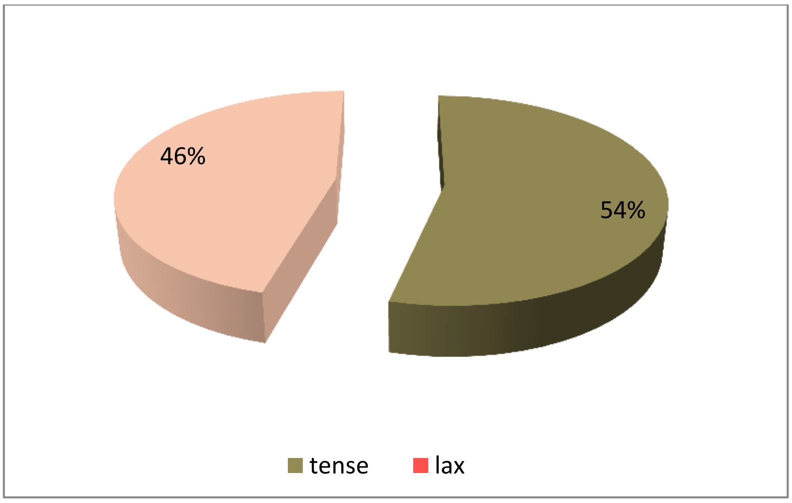

Figure 23: Pie chart showing percent tenseness of laugh in HI males.

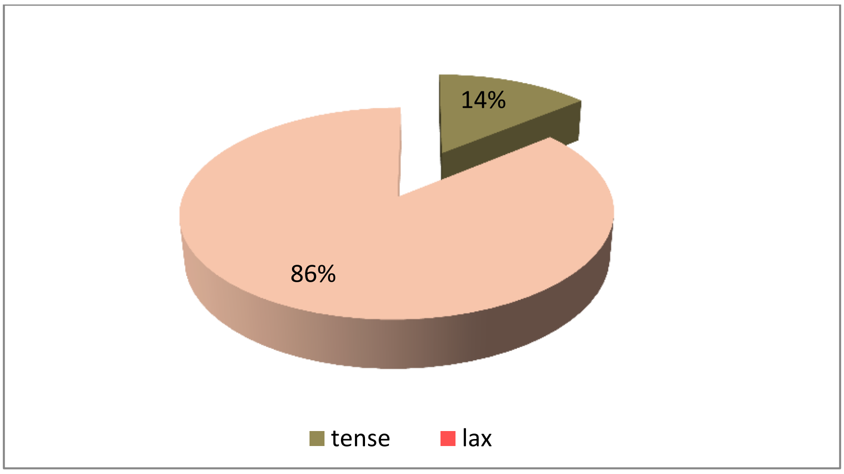

Figure 24: Pie chart showing percent tenseness of laugh in normal females.

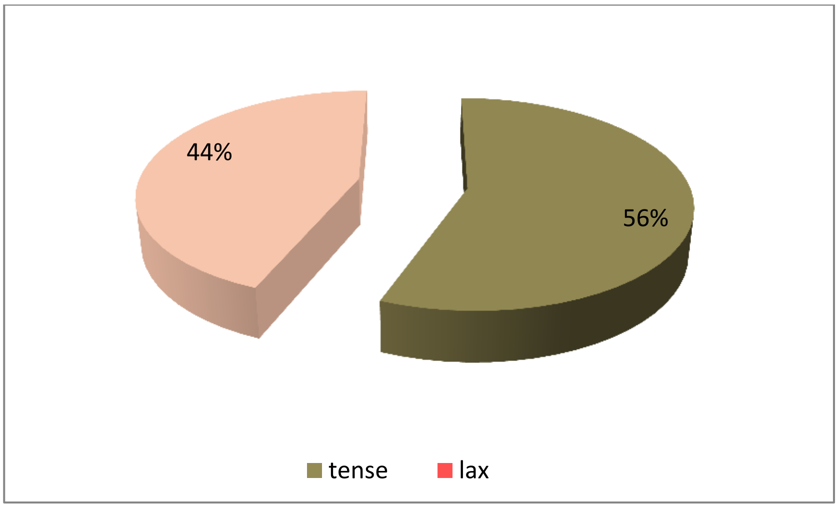

Figure 25: Pie chart showing percent tenseness of laugh in HI females.

10. Nasality

Majority of laughs produced by normal individuals were non nasal (Males -97%, Females – 94%). On the contrary, majority of laughs in PHI were nasal (Males - 56 %, Females - 64%) compared to their normal peers. Table 10 and figures 24-27 shows percent nasality of laughs in both the groups.

	Males		Females	
	N	NN	N	NN
Group I	56	44	64	36
Group II	3	97	6	94

Table 10: Percent nasality of laughs in both groups (N= Nasal, NN = Non nasal).

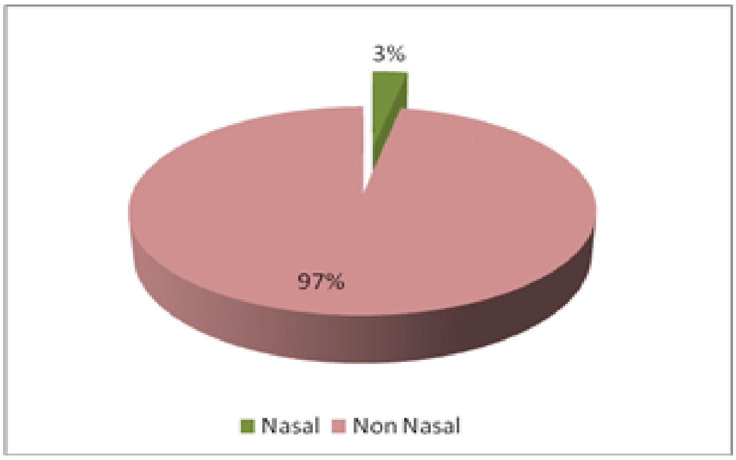

Figure 26: Pie chart showing percent nasality of laugh in normal males.

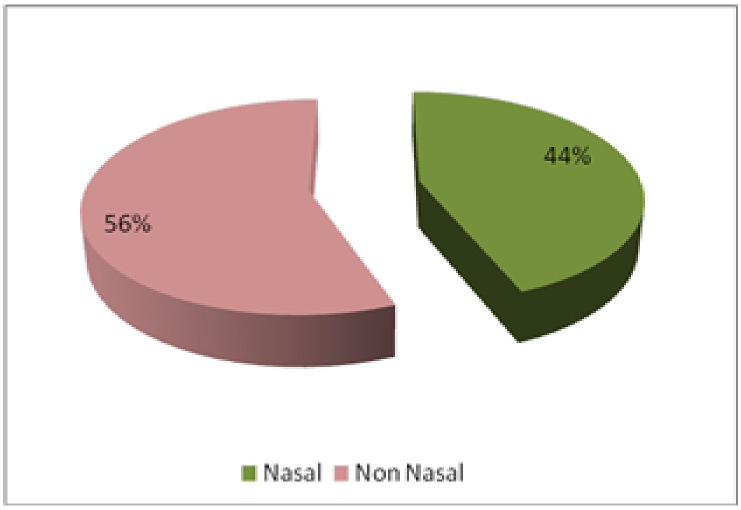

Figure 27: Pie chart showing percent nasality of laugh in HI males.

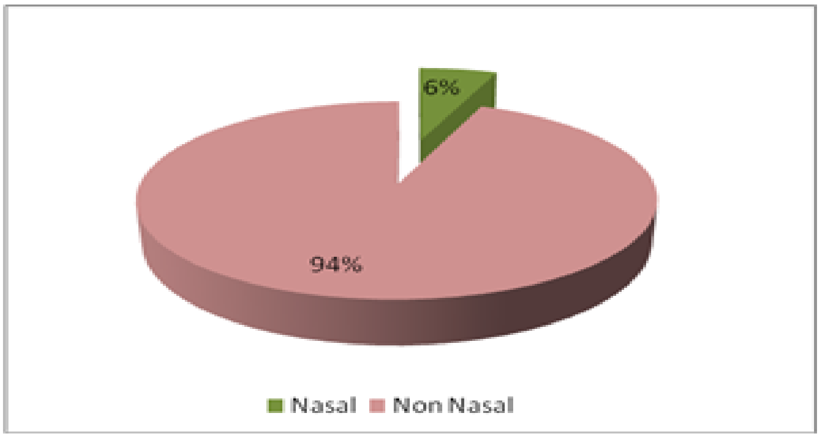

Figure 28: Pie chart showing percent nasality of laugh in normal females.

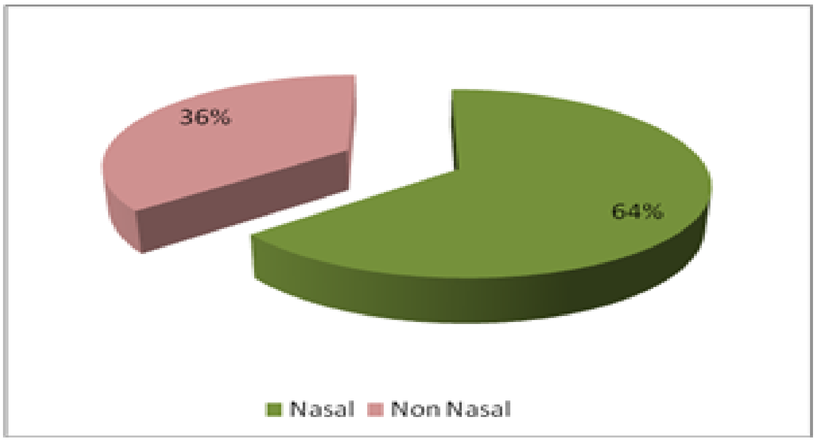

Figure 29: Pie chart showing percent nasality of laugh in HI females.

Since some of the interactions were significant in two-way MANOVA, following analysis were administered for the detailed study of interactions.

One way MANOVA to study interaction of group within each gender.

One way MANOVA to study interaction of gender within each group.

One way MANOVA did not reveal any difference in trends. The result matched with the main effect of group and gender showing significant effect of group and gender in every parameter ($P < 0.001$).

CHAPTER V

DISCUSSION

The results indicated several points of interest. **First** of all, the average F0, minimum F0 and maximum F0 were significantly lower in PHI compared to normal adults. This is in consonance with the results of the study done by Reuben and Savithri (2012). Furthermore, the study by Angelocci et al. (1964) has shown that a large number of PHI exhibit abnormal pitch patterns compared to normal individuals. In addition, as a result of not being able to monitor their own production, PHI might be self- conscious about the quality of their vocalizations fearing that they may sound "funny" (Higgins, 1980). In the present study also, this sort of social conditioning may have produced vocal suppression among hearing impaired participants. Also, PHI tend to soften laughter sounds by keeping their mouth closed, producing laughter that might normally be associated with low arousal emotional responses even when they are experiencing more intense laughter. In addition, PHI tends to use sign language more predominantly and the aspects of humour can be different compared to normal speech. If so, likely effects would include lower mean, minimum and maximum F0 values compared to their normal peers during laughter as seen in the present study.

Second, the F0 range was lower in PHI compared to normal adults during laughter. This indicates insufficient use of respiratory and laryngeal subsystems in PHI. In the present study also, PHI might have exhibited inadequate use of residual lung capacity and breathlessness was noticed during their laughter leading to reduced F0 range. Savithri (2000) reported that normal males used F0 higher than the habitual F0 during laughter. Nevertheless, the same was not found in the present study in males with HI. Normal males may use F0 higher than habitual as they use a range of frequencies and need to produce lower F0. However, in PHI this may not be so as the F0 range was significantly lower in PHI compared to normal adult males.

Third, percentage of half voiced laugh was more than that of voiced or unvoiced in normal individuals. This is in consonance with the study done by Savithri (2000) who also report a greater number of half- voiced laughs in normal individuals. It was interesting to note that voicing of laughs were different in PHI compared to normal adults. While normal adults produced 95% (males) and 93% (females) half voiced laughs, PHI produced 72% (males) and 66% (females) half voiced laughs, and had 28% (males) and 34% (females) unvoiced laughs, respectively. The results of the study are also in consonance with the study done by Reuben and Savithri (2012) who reported the presence of more unvoiced laughs in PHI. This difference may be attributed to the deficiencies in laryngeal and oral motor control and relatively low rates of vocalization occurring in profoundly HI individuals. Vocal anatomy in PHI tested here may be affected by similar constraints. The other reason could be that PHI may have been diligently inhibiting their vocal responses. While amplitudes of infant vocalizations are not found to differ for hearing impaired and deaf babies (Oller, Eilers, Bull & Carney, 1985), hearing impaired adults report being conscious about vocalizing too loudly and that they feel societal pressure to avoid doing so (Leder & Spitzer, 1993) . Lack of proper auditory feedback might be another likely cause for the more percentage of unvoiced laughs in PHI. Females with hearing impairment producing more unvoiced laughs compared to their male counterparts may be due to the fact that they might be less stimulated by the laughter induction movie clips, or were showing suppression of their vocal responses to that material. Emotional contagion could also have played a role in the testing situations. In PHI, the trigger for laughter could only be due to the visual representation of funny scenes from movie clips, while in hearing participants, both sight of the funny incident and sound of laughter could be involved. Thus the outbreak of laughter resulting from visual stimulation alone would be less than that from the combination of both visual and auditory effects. If so, this difference could also have contributed to the PHI experiencing less intense response to the material presented compared to hearing participants. This may provide justification for the popularity of laugh tracks in comedy television shows. This study partially refutes the notion of laugher being innate and biologically grounded (Black, 1984; Eibl-Eibesfeldt, 1989) and direct auditory experience with this vocalization is necessary for it to emerge in species typical form.

Fourth, majority of the melody patterns in laughter were falling type in both the groups. Physiologically this indicates a descent of the larynx during laughter. Lushsinger & Arnold (1965) and Savithri (2000) also reported more falling type melody pattern in normal individuals. However, in the present study it was found that the falling pattern was slightly reduced in PHI which might be attributed to no or reduced descent of the larynx during laughter in PHI. Another interesting aspect that emerged out of this study was some of PHI (both gender) produced flat melody patterns which were not found in the normal individuals. The reason might be due to the presumed faulty breath control thus interrupting the natural flow of laughter.

Fifth, duration between successive laughs was significantly longer in PHI compared to normal adults. This is in consonance with the study done by Makagon et al. (2008) who also report longer duration in successive laughs of PHI. Researchers investigating vocal production in hearing impaired talkers have also suggested that laryngeal and oral deficits can alter the temporal characteristics of their speech – slower, elongated vowels in the speech of PHI (LaPointe et.al, 1990; Bakkum et al. 1995; Okalidou & Harris, 1999). Since laughter is close to speech and is produced by the same physical system, the human vocal tract, the temporal parameters of laughter may also be affected in PHI. Also, the longer duration between laughter in PHI, could be analogous to the interphonemic and intersyllabic temporal distortions found in speech of PHI (Rothman, 1976).

Sixth, F_1 and F_3 in the laughs of PHI were significantly lower and F_2 was higher compared to that in normals. This is in consonance with the study done by Reuben and Savithri (2012) who reported similar findings in the laughter of children with hearing impairment. Jeyalakshmi, Krishnamurthy and Revathy (2010) also reported variation in pitch and formants for deaf children compared to normals. Studies on vowel production by English-speaking profoundly hearing impaired children have reported formant frequencies deviating from normal values (Angelocci et al., 1964). Limited control of tongue shape by speakers with profound hearing loss has been reported in studies of tongue movement using glossometric technique (Dagenais & Critz-Crosby, 1992), as well as electromyographic technique (Elfenbein, Hardin-Jones & Davis, 1994). This indicates that PHI use a relatively more neutral and less distinctive tongue configuration compared to normal peers. This may be due to the fact that speakers with profound hearing loss have difficulty in perceiving the acoustic cues of vowel identity. The reduction in F_1 and the increased F_2 in PHI indicate lower and fronted tongue position which might reflect the fact that PHI may rely mainly upon visual information to perceive and produce vowel. The fact that tongue height and lip configuration are more easily seen than front-back placement could account for the fact that PHI learnt to produce vowel like laughs in a fronted tongue position and thus were able to produce almost distinct F_1, but not F_2, values for the vowels in the present study.

Seventh, the laughs produced by PHI were more discontinuous compared to their normal peers. This might be due to the due to improper control of the closing of the vocal cords and the respiratory constraints seen in PHI. McGarr and Lofqvist (1982) found that PHI exhibit inappropriate glottal abduction between the words. Hence, similar factors might also have played a role in the laughter in PHI.

Eighth, PHI produced reduced number of bouts compared to normal individuals indicating reduced use of expiratory air in PHI. This is in consonance with the study done by Reuben and Savithri (2012) who reported children with Hearing impairment exhibiting reduced number of bouts compared to normal children. **Ninth**, Majority of laughs produced PHI were tense compared to their normal peers. Normal persons exhibited less tenseness – 12 % (males) and 14 % (females) in their laughs indicating better laryngeal muscular coordination. In PHI laughs, more strain in their neck muscles due to the excessive laryngeal muscle activity might be observed. Also F0 in PHI laughter was higher compared to their phonation. Furthermore, PHI tended to expend a lot of energy in producing laughter which might have led to more tense laughs. Higgins et al. (1980) also reported that the hyperconstriction of the glottis was adopted to increase tactile feedback in PHI. In the present study also, all these reasons might have led to more tenseness in the laughs of PHI.

Finally, PHI had significantly more number of nasalized laughs compared to their normal peers. The main underlying physical variable defining the degree of nasality in normal speech is the movement of the velum between the oral and the nasal vocal tract. Excessive nasality is often observed in the speech of PHI due to faulty velopharyngeal mechanism because these individuals cannot adequately monitor these subtle characteristics of speech (Fletcher & Higgins, 1980). Improper mouth opening, as well as the faulty lowering of the soft palate, might also contribute to resonance problems in PHI. Furthermore, the improper velopharyngeal timing might also result from the poor auditory feedback in PHI (Waldstein, 1990). In the present study also, these structural limitations might have played a role in PHI accounting for more number of nasality in their laughs.

To summarize, PHI had significantly lower mean F0, minimum F0, maximum F0 and F0 range compared to normal adults. Further PHI had less half- voiced laughs and more unvoiced laughs compared to normal adults. Majority of the melody patterns were falling in both PHI and normal adults. Duration between successive laughs was significantly longer in PHI compared to normal adults. F_1 and F_3 were significantly lower and F_2 was significantly higher in PHI laughs compared to normal adults. Also laughs were more discontinuous, had reduced number of bouts, tensed and were nasalized in PHI compared to normal adults. The results of the present study have contributed to the literature on laughter in PHI. However, it can be viewed as a first step. Future research in the areas of development of laughter in PHI and laughter in post- lingual PHI is warranted.

CHAPTER VI

SUMMMARY AND CONCLUSIONS

The present study investigated laughter acoustics in college students with and without hearing impairment. Laughter of fifteen male and fifteen female college students with HI (Severe/ Profound SNHL) in the age range of 18-26 years, and age and gender matched normal adults were elicited using funny movie clips and compared with age and gender matched normal peers. All PHI were hearing aid users (Behind the Ear-digital) since four years of age and were still continuing to use hearing aids and had attended speech therapy for a minimum of 5 years. The laughs were stored separately for each speaker onto a computer memory at mono channel, 16 bit resolution and 44 KHz sampling rate using PRAAT -5114 software (Boersma & Weenick, 2009). The laughs were depicted as waveform, pitch contour and wide band bar type spectrograms. The various acoustic measures that were performed included average frequency, highest and lowest frequency, voicing, melody type, duration between successive /ha/ laughs, formant frequencies, continuity, nasality and tenseness.

The results indicated several points of interest. First of all, the average F0, minimum and maximum F0 were significantly lower in PHI compared to normal adults. As a result of not being able to monitor their own production, PHI might be self- conscious about the quality of their vocalizations fearing that they may sound facetious. Moreover, PHI tend to dampen laughter sounds by keeping their mouth closed, producing laughter that might normally be associated with low arousal emotional responses even when they are experiencing more intense laughter. Furthermore, PHI tends to use sign language as a primary mode of communication and the aspects of humour can be radically different compared to normal speech. If so, possible effects would lead to lower mean, minimum and maximum F0 values compared to their normal peers as seen in the present study.

Second, the F0 range was lower in PHI compared to normal adults during laughter. This indicates insufficient use of respiratory and laryngeal subsystems in PHI. In the present study also, PHI might have exhibited insufficient use of residual lung capacity and breathlessness was noticed during their laughter contributing to reduced F0 range.

Third, it was enthralling to note that voicing of laughs were different in both groups. PHI produced less half voiced laughs and more unvoiced laughs compared to the normal hearing peers. This difference may be attributed to the deficiencies in laryngeal and oral motor control and relatively low rates of vocalization occurring in profoundly HI individuals. The other reason could be that PHI may have been consciously inhibiting their vocal responses. Lack of proper auditory feedback might be another likely cause for the more percentage of unvoiced laughs in PHI. Emotional contagion could also have played a role in the testing situations. In PHI, the trigger for laughter could only be due to the visual representation of funny scenes from movie clips, while in hearing participants, both sight of the funny incident and sound of laughter could be involved. Thus the outburst of laughter resulting from visual stimulation alone would be less than that from the combination of both visual and auditory effects. If so, this difference could also have contributed to the PHI experiencing less intense reaction to the material presented compared to hearing participants.

Fourth, majority of the melody patterns in laughter were falling type in both the groups in the present study. However, it was found that the falling pattern was slightly reduced in PHI which might be attributed to no or reduced descent of the larynx during laughter in PHI. Another exciting aspect that emerged out of this study was some of PHI (both gender) produced flat melody patterns which were not found in the normal individuals. The reason might be due to the presumed faulty breath control thus interrupting the natural flow of laughter.

Fifth, duration between successive laughs was significantly longer in PHI compared to normal adults. The laryngeal and oral deficits seen in PHI might have altered the temporal characteristics of their laugh sounds.

Sixth, F_1 and F_3 in the laughs of PHI were significantly lower and F_2 was higher compared to normal adults. This indicates that PHI use a relatively more neutral and less distinctive tongue configuration compared to normal peers. Also, speakers with profound hearing loss have difficulty in perceiving the acoustic cues of vowel identity. The fact that tongue height and lip configuration are more easily seen than front-back placement, could account for the fact that PHI learnt to produce vowel like laughs in a fronted tongue position being able to produce almost distinct F_1, but not F_2 values for the vowels in the present study.

Seventh, the laughs produced by PHI were more discontinuous compared to their normal peers. This might be due to the due to improper control of the closing of the vocal cords and the respiratory constraints seen in PHI.

Eighth, PHI produced reduced number of bouts compared to normal individuals indicating reduced use of expiratory air in PHI. Ninth, Majority of laughs produced PHI were tense compared to their normal peers. In PHI laughs, more strain in their neck muscles due to the excessive laryngeal muscle activity might be observed.

Furthermore, PHI tended to expend a lot of energy in producing laughter which might have led to more tense laughs. In the present study also, all these reasons might have contributed to more tenseness in the laughs of PHI.

Finally, PHI had significantly more number of nasalized laughs compared to their normal peers. Excessive nasality is often observed in the speech of PHI due to faulty velopharyngeal mechanism because PHI cannot adequately monitor these subtle characteristics of speech. Improper mouth opening, as well as the faulty lowering of the soft palate, might also contribute to resonance problems in PHI. Furthermore, the improper velopharyngeal timing might also result from the poor auditory feedback in PHI. Even in laughter also, these structural limitations might have played a role in PHI accounting for more number of nasality in their laughs.

The results of this study have contributed to the literature on laughter acoustics. Laughter is a constituent of human behaviour regulated by the brain. It helps humans elucidate their meanings in social interaction and gives an emotional context to conversations. Laughter is used as an indication for being part of a society - it signals compliance and positive interactions with others. Laughter is usually contagious, and the laughter of one person can incite laughter from others as a positive feedback. So it is interesting to know how laughter acoustics varies among hearing impaired and normal adults. Auditory experience, whether sounds produced by others or by the vocalizers themselves, is necessary for recognizable laughter. Whilst this work is one of the few studies exploring on the in-depth analysis of laughter in PHI and comparing it with normal individuals in the Indian scenario, it nonetheless illustrates that laughter can be recorded from PHI under controlled circumstances and fruitfully compared to sounds produced by normal hearing controlled participants. Refining and expanding the techniques along with more number of samples may make this overall approach a potent tool in the larger endeavour of achieving a scientific understanding of the acoustics of human laughter. Future research on development of laughter in PHI and laughter in post-lingual PHI is warranted.

References

Angelocci, A., Kopp, G., & Holbrook, A. (1964). The vowel formants of deaf and normal hearing eleven to fourteen year old boys. *Journal of Speech and Hearing Disorders*, *29*(1), 156-170.

Apte, M. L. (1985). *Humor and laughter: An anthropological approach.* Ithaca: Cornell University Press.

Bachorowski, J. A., Smoski, M. J., & Owren, M. J. (2001). The acoustic features of human laughter. *Journal of the Acoustical Society of America, 110*(2), 1581-1597.

Bakkum, M. J., Plomp, R., & Pols, L. W. (1995). Objective analysis and subjective analysis of vowels pronounced by deaf and normal hearing children. *Journal of the Acoustical Society of America, 98*(1), 755-762.

Bickley, C., & Hunnicut, S. (1992). Acoustic analysis of laughter. *Proceedings of the Second International Conference on Spoken Language processing*. New Jersey: Erlbaum.

Black, D. W. (1984). Laughter. *Journal of American Medical Association, 252*(1), 2995-2998.

Boersma, P., & Weenick, B. (2009). Praat: doing phonetics by computer (Version 5.1.14) [Computer program]. Retrived from http://www.praat.org.

Bright, K. E., Hixon, T., & Hoit, D. (1986). Respiration as a laughing matter. In D. L. Nilsen (Eds.), *Whimsy* (pp.147-148). New York, NY: Guiliford Press.

Citardi, M. J., Yanagisawa. E., & Estill. G. (1996). Video endoscopic analysis of laryngeal function during laughter. *Annals of Otology, Rhinology, and Laryngology, 105*(2), 545-549.

Dagenais, P., Critz-Crosby, P., Fletcher, S., & McCutcheon, M. (1992). Comparing abilities of children with profound hearing impairments to learn consonants using electropalatography or traditional aural-oral techniques. *Journal of Speech and Hearing Research, 37*(2), 687-699.

Darwin, C. H. (1872). *The Expression of the Emotions in Man and Animals* (3rd ed.). London: Oxford University Press.

DeTroyer, A., Ninane, J. J., Gilmartin, C., & Estenne, M. (1987). Triangularis sterni muscle use in supine humans. *Journal of Applied Physiology, 62*(1), 919-925.

Eibl-Eibesfeldt, I. (1989). *Human Ethology* (2nd ed.). New York: Aldine Transaction.

Elfenbein, J., Hardin-Jones, M., & Davis, J. (1994). Oral communication skills of children who are hard of hearing. *Journal of Speech and Hearing Research, 37*(2), 216-226.

Fletcher, S., & Higgins, J. (1980). Performance of children with severe to profound auditory impairment in instrumentally guided reduction of nasal resonance. *Journal of Speech and Hearing Disorders, 45*(1), 181-194.

Forner, L., & Hixon T. J. (1977). Respiratory kinematics in profoundly hearing impaired speakers. *Journal of Speech and Hearing Disorders, 18*(1), 22-29.

Grammar, K., & Eibl-Eibesfeldt, I. (1990). The ritualization of laughter. In Acta Colloquii, (Eds.), *Laughter (*pp. 192-214). Bochum: Brockmeyer.

Habbermann, G, (1955) cit. in Luchsinger, R. L, & Arnold, G. E, *Voice, Speech and Language* (2nd ed.). London: Constable.

Hall, G. S., & Allin, A. (1897). The physiology of tickling, laughing and comic. *American Journal of Psychology, 9*(1), 31-41.

Higgins, P. C. (1980). *Outsiders in a Hearing World: A Sociology of Deafness* (3rd ed.).Beverly Hills: Sage Publication.

Hoit, J. D., Plassman, B. L., Lansing, R.W., & Hixon, T. J. (1988). Abdominal muscle activity during speech production. *Journal of Applied. Physiology, 65*(3), 2656-2664.

Jacob, J., Chandrasekhra, A., & Kumar, R. (2011, January). *Formant characteristics of laughter in children.* Poster presented at the 43rd annual convention of Indian Speech and Hearing Association, Kolkota.

Jeyalakshmi, C., Krishnamurthi. V., & Revathy, A. (2010). Speech recognition of deaf and hard of hearing people using hybrid neural network. *Signal & Image Processing : An International Journal , 10*(1), 14-25.

Kovi, S. (1987). Perceptual dimensions of laughter and their acoustic correlates. *Proceedings of the XIth International congress of Phonetic Sciences*, Tallin, Sec 67.4.1, pp. 255-258.

Ladd, P. (2003). *Understanding deaf culture: In search of Deafhood* (2nd ed.). Toronto: Multilingual Matters.

LaPointe, L. L., Mowrer, D. M., & Case, J. L. (1990). A comparative acoustic analysis of the laugh responses of 20 and 70 year old males. *International Journal of Aging Human Behaviour, 31*(1), 1-9.

Laughter. (2010). In *Encyclopaedia Britannica online.* Retrived from http://www. britannica.com//laughter.

Leder, S. B., & Spitzer, J. B. (1993). Speaking fundamental frequency, intensity and rate of adventitiously profoundly hearing impaired adult women. *Journal of the Acoustical Society of America*, *93*(1), 2146-2151.

Lloyd, E. L. (1978). The respiratory mechanism in laughter. *Journal of General Psychology*, *19*(1), 79-189.

Lucas, C., Bayley, R., & Valli, C. (2001). *Sociolinguistic variation in American Sign Language*. Washington, DC: Gallaudet University Press.

Luschei, E. S., Ramig, K., Baker. J., & M. Smith. (1997). *Coordination of the laryngeal and respiratory systems during spontaneous laughter*, Unpublished Manuscript, Department of Speech Pathology, University of Iowa, Iowa City, USA.

Lushinger, R., & Arnold, G. E. (1965). *Voice, Speech and Language,* Belmont, CA: Wadsworth Publishing Company, Inc.

Makagon, M. M., Funayama, S. E., & Owren, M. J. (2008). An acoustic analysis of laughter produced by congenitally deaf and normally hearing college students. *Journal of Acoustic Society of America, 124*(1), 472-483.

McGarr, N., & Lofquist, A. (1982). Obstruent production by hearing-impaired children speakers: Interarticulator timing and acoustics. *Journal of the Acoustical Society of America*, *72*(1), 34-42.

Milford, P. A. (1980). *Perception of laughter and its acoustical properties* (Report No.12). Department of Speech Communication. Pennsylvania. Autumn House Press.

Monsen, R. B. (1978). Towards measuring how well hearing impaired children speak. *Journal of Speech and Hearing Research, 17*(2), 386-398.

Moore, P., & Von Leden. H. (1958). Dynamic variations of the vibratory pattern in the normal larynx. *Folia. Phoniatrica, 10*(1), 205-238.

Mowrer, D. E. (1994). A single case study of perceptual and acoustic features of an infant's first laugh utterances. *Humor, 7*(1), 139-155.

Mowrer, D. E., LaPointe, L. L., & Case. J. (1987). Analysis of five acoustic correlates of laughter. *Journal of Nonverbal Behaviour, 11*(2), 191-199.

Niemitz, C. (1990). Evolution of laughter. *Zoology Seminars. 12*(2), 323-336.

Nwoakh, E. E., Davis, P., Hsu, H. C., & Fogel, A. (1993). Vocal affect in 3-year-olds: A quantitative acoustic analysis of child laughter. *Journal of the Acoustical Society of America, 94*(2), 3076-3090.

Nwokah, E. E., Davis, P., Hsu, H. C., & Fogel, A. (1999). The integration of laughter and speech in vocal communication: A dynamic systems perspective. *Journal of Speech Language and Hearing Research, 42*(1), 880-894.

Okalidou, A., & Harris, K. S. (1999). A Comparison of inter gestural patterns in deaf and hearing adult speakers: Implications from an acoustic analysis of disyllables. *Journal of the Acoustical Society of America, 106*(1), 394-410.

Oller, D. K., Eilers, R. E., Bull, D. H., & Carney, A. E. (1985). Pre speech vocalizations of a deaf infant: A comparison with normal metaphonological development. *Journal of Speech Language and Hearing Research, 28*(1), 47-63.

Osberger, M. J., & McGarr, N. S (1983). Speech production characteristics of the hearing impaired. In. N. Lass (Ed.), *Speech and Language: Advances in Basic Research and Practice (*pp. 221-283). NewYork: Academic Press.

Owren, M. J., & Bachorowski, J. A. (2003). Reconsidering the evolution of nonlinguistic communication: The case of laughter. *Journal of Nonverbal Behavior, 27*(2), 183-200.

Owren, M. J., & Rendall, D. (1997) An affect-conditioning model of nonhuman primate vocal signaling. In D. H. Owings, M. D. Beecher, & N. S. Thompson (Eds.), *Perspectives in Ethology*: Vol. 12. Communication (pp. 299-346). New York: Plenum Press.

Padden, C. A., & Humphries, T. L (1990). *Deaf in America: Voices from a Culture*, Cambridge: Harvard University.

Papousek, H., Papousek, M., & Koester, L. S. (1986). Sharing emotionality and sharing knowledge. In C.E. Izard & P. Read (Eds.), *Measuring emotions in infants and children* (Vol.2, pp. 93-123). Cambridge, England: Cambridge University Press.

Pearce, J. (2004). Some neurological aspects of laughter. *European Neurology, 52(1),* 169-171.

Provine, R. R. (1993). Laughter punctuates speech: Linguistic, social, and gender contexts of laughter. *Etholology, 95*(1), 291-298.

Provine, R. R. (2000). *Laughter: A Scientific Investigation,* NewYork: Viking Publications.

Provine, R. R., & Emmorey, K. (2006). Laughter among deaf signers. *Journal of Deaf Studies and Deaf Education, 11*(2), 403-409.

Provine, R. R. & Yong, Y. L. (1991). Laughter: A stereotyped human vocalization, *Ethology , 89*(1), 115-124.

Rankin, A. M., & Philip, P. J. (1963). An epidemic of laughing in the Bukobha district of Tanganyika. *Central African Journal of Medicine, 12*(1), 167-170.

Rendell. D., Kollias. S., Lloyd. P., & Ney. C. (2005). Pitch and formant profiles of human vowels and vowel-like grunts: the role of vocalizer body size and voice-acoustic allometry. *Journal of Acoustic Society of America, 117*(2), 944-955.

Reuben, T. V., & Savithri, S. R. (2012, January). *Comparative study of laughter acoustics in adults with and without hearing impairment*. Poster presented at the 44th annual convention of Indian Speech and Hearing Association, Hyderabad.

Reuben, T. V., & Savithri, S. R. (2012). Formant frequencies of laughter in children with and without hearing impairment. *Proceedings of the International Symposium on Frontiers in Speech and Music,* pp. 81-84. Gurgaon: KIIT Press.

Rothman, H. B. (1976). A spectrographic investigation of consonant vowel transitions in the speech of deaf adults. *Journal of Phonetics, 4*(2), 129-134.

Ruch, W & Ekman, P. (2001). The expressive pattern of laughter. In A. Kaszniak (Ed.) *Emotion, qualia and consciousness,* 426-443, Tokyo: World Scientific Publishers.

Savithri, S. R. (2000). Acoustics of Laughter. *Journal of the Acoustical Society of India, 28*, 233-238.

Szameitat, D., Darwin, C., Szameitat, A., & Alter, K. (2010). Formant characteristics of Human Laughter. *Proceedings of the Interdisciplinary Workshop on The Phonetics of Laughter,* pp. 9-13, Germany: Saarbrucken.

Szameitat, D., Darwin, C., Szameitat, A., & Alter, K. (2011). Acoustic correlates of emotional dimensions in laughter: Arousal, dominance, and valence. *Cognition and Emotion, 25*(4), 599-611.

Schrotter, H. (1985). Respiratory mechanism in laughter. *Laryngo-Rhinology, 59*(1), 82-108.

Svebak, S. (1975). Respiratory patterns as predictors of laughter. *Psychophysiology, 12*(1), 62-65.

Van Hooff, J. A. (1972). A comparative approach to the phylogeny of laughter and smiling. In R.A. Hinde (Eds.), *Non-verbal Communication (*pp. 209-241). Cambridge: Cambridge University Press.

Vettin, J., & Todt, D. (2004). Laughter in conversation: Features of occurrence and acoustic structure. *Journal of Nonverbal Behaviour*, *28*(1), 93-115.

Waldstein, R. S. (1990). Effects of postlingual deafness on speech production: Implications for the role of auditory feedback. *Journal of the Acoustical Society of America*, *88*(1), 220 -229.