Manipulation of hearing aid gain and tinnitus relief: A paired comparison study

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This Dissertation is submitted as part fulfillment

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University of Mysore, Mysore

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Certificate

This is to certify that this Masters dissertation entitled '**Manipulation of hearing aid gain and tinnitus relief: A paired comparison study**' is a bonafide work in part fulfillment for the degree of Master of Science (Audiology) of the student with Registration Number 14AUD023. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other Universities for the award of any Diploma or Degree.

Mysuru,

May, 2016

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Declaration

This Masters dissertation entitled **'Manipulation of hearing aid gain and tinnitus relief: A paired comparison study'** it is the result of my own study and has not been submitted to any other university for the award of any other Diploma or Degree.

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Abstract

Objective: The study aims to investigate the best amplification strategy for tinnitus relief without compromising speech perception. The objectives were formulated as follows:

1) To compare amplification strategies on tinnitus relief using paired comparison method

2) To measure SNR 50 from three amplification strategies to document speech perception ability. **Method**: A repeated measure research design was utilized. Twelve participants in the age range of 30-60 years who had mild to moderately severe sloping sensorineural hearing loss with continuous tonal tinnitus were considered. The participants were grouped into mild and severe based on score obtained in Tinnitus Handicap inventory (THI). In each participant, minimum masking level (MML) was used to assess tinnitus pitch and loudness. A paired comparison method was carried out to select the best program on tinnitus relief and SNR 50 was done to obtain speech perception ability. MML which is the level of noise required to mask tinnitus as a function of frequencies were obtained. A paired comparisons method was carried out to determine the program in which maximum preference score obtained on tinnitus relief by a test hearing aid which was programmed with three programs such as prescriptive, preferred and adjusted gain at tinnitus pitch. In addition, SNR 50 was obtained to determine speech perception skills in each program. **Result**: Each group of participants' significantly preferred hearing aid gain set at tinnitus pitch on tinnitus relief. There was no significant difference between the SNR 50 scores in the three gain settings. **Conclusion**: An additional gain set at tinnitus pitch after alleviating hearing loss by prescriptive method was found to be the best

strategy for effective masking of tinnitus and that led to tinnitus relief without compromising speech perception.

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Chapter 1

Introduction

Tinnitus is a sound produced without any external stimulus which originates in the head (Mc Fadden, 1982). Tinnitus is majorly associated with either unilateral or bilateral hearing loss (Kim et al, 2015). Assessment of tinnitus pitch and loudness necessitates in initiating with any rehabilitation program. Minimum Making Level (MML) is one such assessment method uses masking method (Feldmann, 1971) to assess tinnitus pitch and loudness. In MML an intensity of narrowband noise required to mask tinnitus was determined across frequencies. Wegal and Lane (1924) observed lowest masking level required at a frequency close to tinnitus pitch.

The management options for tinnitus includes tinnitus retraining therapy, tinnitus habituation therapy, tinnitus masking equipments (sound generators), hearing aid, notch music therapy, etc. Hearing aids have been considered as a useful tool in tinnitus management (Saltzman & Ersner, 1947). Kicssling (1980) compared hearing aids with maskers for the treatment of tinnitus and concluded that usage of hearing aids was efficient in suppressing tinnitus. This is because hearing aids acts as a masker; reduce awareness on tinnitus; they may facilitate better communication, reduces stress (Newman, 1999; Del Bo & Ambrosetti, 2007); and they may directly act against tinnitus source of generation by reducing drivers of central gain adaptation or inhibition (Moffat et al, 2009).

Modifications in the hearing aid add a meaningful approach on tinnitus relief. Choosing the right fitting formula for individuals with tinnitus is one of the important approaches. In a comparison between DSL (I/O) v4.0 and NAL-NL1 prescription formulae, 80 % of the individuals with tinnitus reported less audibility of tinnitus when the hearing aid was programmed using DSL (I/O) v4.0 (Wise 2003). The reason could be a higher low frequency gain is provided especially when they are of low intensities sound (Dillion, 2001). This might have allowed the low frequency ambient noise to sufficiently be audible and mask the tinnitus to a certain extent.

The flexibility of current hearing aid technologies lead to the development of fitting approaches specifically intended for the reduction of tinnitus. The fitting of open ear devices in the treatment of tinnitus has been shown to be as effective (Del Bo & Ambrosetti, 2007). Wise (2003) varied the compression threshold in hearing aid and its effect on audibility of tinnitus was assessed. Low compression knee-point of 30 dB SPL produced ambient noise significantly louder than compared to compression threshold set at 50 dB SPL.

May (1998); Ricketts and Mueller (1999) assisted the patients to change the options of sensitivity of microphones, noise reduction circuit and volume control who wishes to hear speech in background noise and to take maximum advantage of diffuse ambient noise for tinnitus management. The participants of the study switched off noise reduction circuit and changed from directional sensitivity of microphone to omnidirectional. In addition, volume control is changed to obtain tinnitus relief.

Despite numerous studies on hearing aid for tinnitus management, none of the studies showed focus on prescribing sufficient gain at tinnitus pitch on tinnitus relief. Swathi, Shetty, Jijo & Narne (2015) studied acoustic stimulation treatment by changing the gain in hearing aid against tinnitus pitch and results revealed that tinnitus is suppressed. It infers that rather than just fitting the hearing aid for their hearing loss, a one step further gain optimization at tinnitus pitch is required for effectively reducing the audibility of tinnitus. However, in their study an attempt was not made in comparing prescribing gain and optimizing gain at tinnitus pitch. Thus, in the present study, a systematic design was utilized to determine the best program to alleviate hearing loss without comprising speech perception and give maximum benefit on tinnitus relief. The following research question was formulated; does gain adjustment at tinnitus pitch lead to tinnitus relief and better speech perception? The present study aimed to compare three gain settings in the hearing aid to arrive at a conclusion that if any of the gain setting can successfully lead to tinnitus relief. Thus, null hypothesis will be none of the gain adjustment strategies in hearing aid has provided tinnitus relief and speech perception scores.

1.1. Need for the study

The hearing aid is one among the treatment option available for tinnitus relief. Acoustic stimulation by the hearing aid prescribed for hearing loss has an effect on tinnitus relief but it is not consistent. This is because there is no standard prescription of gain in hearing aid for management of tinnitus. Thus, an attempt was made in the present study to adjust gain in hearing aid in a systematic manner with respect to tinnitus pitch. This kind of gain management in hearing aid could stimulate the neural activity throughout the auditory system and consequently suppress the source generation of tinnitus effectively at central auditory system without comprising speech perception scores.

1.2. Aim

Aim of the study was to investigate manipulation of gain in hearing aid on tinnitus relief and speech perception ability.

1.3. Objectives

The following objectives are utilized in each group to investigate the aim of the study

1. To document the minimum masking level on tinnitus suppression.
2. To find the relation between MML at tinnitus pitch and gain at tinnitus pitch.
3. To record output of hearing aid at tinnitus pitch from each program strategy (Prescriptive, preferred and adjusted gain at tinnitus pitch) for evaluating gain differences.
4. To compare amplification strategies on tinnitus relief using paired comparison method.
5. To measure SNR 50 from three amplification strategies to document speech perception ability.

Chapter 2

Literature Review

The focus of the study was to investigate the effect of gain manipulation in a hearing aid on tinnitus relief. In relation to the aim and objectives of the study, relevant studies on the topic were reviewed and it is discussed under the following headings:

1. Prevalence and Incidence of Tinnitus
2. Tinnitus Assessment: Minimum Masking Levels
3. Tinnitus Outcome Measures
4. Tinnitus Management
5. Hearing Aids and Tinnitus Relief
6. Optimization of Hearing Aids on Tinnitus Relief

2.1. Prevalence and Incidence of Tinnitus

In India, it is approximated that 4.5 millions of patients are suffering from tinnitus (retrieved from www.tinnex.in).An extrapolated value is that, out of 1,065,070,607 people in India, 47,928,177 have tinnitus(Prakash, Kumar, & Varudhini, 2013). Thirunavukkarasu and Geetha (2013) conducted a one year prevalence study on tinnitus. They revealed that out of 1766 participants with tinnitus, 25.7% were geriatric aged 60 years and above; and hearing loss was reported in 97.5% of these individuals. Out of those individuals about 28.53% had moderate to moderately severe hearing loss. It infers that tinnitus is most common in advanced age with hearing impairment in them. Similar reports are available in Western population. Tinnitus is associated with presbyacusis. (Zagólski & Stręk, 2016), for those aged 50 years and above the prevalence reach up to

20.1% (Hoffman & Reed , 2004).The prevelance of tinnitus increases with increasing age (Kim et al 2015). Shulman (1991) reports of the term *presbytinnitus* specific for the presence of tinnitus in older adults and reflecting cochleovestibular dysfunction.

According to a survey conducted by the National Center for Health Statistics, tinnitus was more common in males than females. Individuals who experience tinnitus generally have hearing loss. The occurrence of tinnitus in isolation is rare. Authors have made an attempt to check for the relationship between tinnitus pitch and their hearing loss. A few of them report that there is no relationship between the tinnitus pitch and the audiogram (Douek, and Reid, 1965, Tyler & Conrad-Armes, 1984), while others have said there is a correlation between tinnitus pitch and the hearing loss. Pan et al. (2016) investigated the relationship between tinnitus pitch and audiograms in 195 individuals. Those individuals whose tinnitus pitch was lower than 2000 Hz had low frequency hearing loss, and those with high pitched tinnitus above 2000 Hz had high frequency hearing loss. The literature review by Goodwin and Johnson (2016) suggest that the loudness of tinnitus is about 5 to 10 dB above their threshold and it can go up to 30-40 dB above their threshold . Nicolas-Puel et al (2002) opine that there is a strong correlation between the loudness of high frequency tinnitus and the elevated thresholds at the high frequency region. To summarize, tinnitus is most prevalent in older adults with hearing loss. There was an equivocal result in predicting tinnitus pitch from hearing loss. The loudness of tinnitus is 5 to 10 dB above their thresholds.

2.2. Tinnitus Assessment: Minimum Masking Level

A systematic investigation of masking phenomena to identify tinnitus pitch and loudness was proposed by Feldmann, 1971.The individuals with tinnitus are presented with narrow band noises of different frequencies and the level of each frequency is increased such that tinnitus is completely masked. The participant was instructed to indicate the intensity of narrow band noise which is just sufficient to mask the tinnitus and this value is the Minimum Masking Level (MML). Similarly this procedure was performed at each frequency and MMLs are plotted as a function of frequencies. The physiology behind this process is lateral inhibition at the neural level. The stimulation from the external source (noise) spreads and reduces the pathological spontaneous activity. The findings of Penner (2016) infer that the level of noise required to mask the tinnitus at the tinnitus pitch is generally the lowest than those at the other frequencies. The masker levels seem to be higher at the high frequencies when compared to the low frequencies (Zwicker, 1974).

It is expected that if tinnitus is higher in intensity, the minimum masking level required is high. But according to the study by Hazel and Graham (1994) there was no correlation between the intensity of tinnitus and MML. A similar result was obtained by Tyler and Conrad-abmes (2016) for which the pattern of noise growth in sensorineural hearing loss, is not well understood.

2.3. Tinnitus Outcome Measures

A qualitative measure of assessing the outcome measures of tinnitus is by administering various questionnaires such as Tinnitus Handicap Inventory (THI), Tinnitus Reaction Questionnaire (TRQ) and Visual Analogue Scale (VAS). THI was developed by Newman and Jacobson (1996), in order to quantify the amount of handicap caused by tinnitus in the daily living. It includes 25 questions, and each question is rated on a three point rating scale ‘yes’ as 4, ‘sometimes’ as 2, and ‘no’ as zero. The maximum score that can be obtained from this test battery is 100. The scoring pattern is 2-16 slight, 18-36 mild, 38-56 moderate, 58-76 severe and 78-100 catastrophic.

Audiologists use the THI as an important measure to assess the effects of tinnitus on the daily routine, emotions and communication skills. Baguley, Humphriss, and Hodgson, (2000) have reported that THI has high convergent validity and is best suited for quantification of self perceived handicap. In yet another study, Baguley and Andersson (2003) concluded that THI has best utility in research and clinical purpose because of its high test retest reliability, high convergent validity, high internal consistency of score and its insight about distress due to tinnitus. Thus,the usage of THI is apt for the study in order gather information regarding the problems on communication, anxiety and the distress caused due to tinnitus.

2.4. Tinnitus Management

Several attempts have been made in order to manage tinnitus as tinnitus retraining therapy, tinnitus habituation therapy, tinnitus masking equipments (sound generators), hearing aid, and notch music therapy. Besides various management options, usage of hearing aids is one of the options to alleviate tinnitus which was proposed by Saltzman and Ersner way back in 1947. However this became clinically applicable only after 30 years through the support of Vernon and associates.

2.5. Hearing Aids and Tinnitus Relief

Numerous studies have recommended the usage of hearing aids on tinnitus relief. A retrospective study by Mcneill, Dayse, Alnafjan, Searchfi, & Welch (2012) analyzed the effect of hearing aid on tinnitus relief. Seventy individuals with tinnitus, who have used hearing aid were analyzed for tinnitus relief. In 37 % of them, tinnitus was totally masked, 40 % reported partial masking, 23% reported no masking, and none reported an increase in loudness of tinnitus. Individuals with high pitch tinnitus generally did not achieve masking. A larger improvement in tinnitus relief were observed for those whose tinnitus pitch fell in the frequency range of the hearing aids with good low frequency hearing and low TRQ (Tinnitus Reaction Questionnaire) scores. In yet another study by Kochkin (2008), who reported 60% of the individuals obtained relief from tinnitus while using hearing aid. Similarly, the reduction in tinnitus was documented on THQ scores after the usage of hearing aid with counseling than those with counseling alone. (Searchfield, Kaur, and Martin, 2010).

According to (Beck, 2011) the probable reasons for which usage of hearing aid for tinnitus relief can be as follows:

- As a result of hearing loss, the neural stimulation is reduced. This leads to hyperactivity in the higher centers of the brain leading to tinnitus. Usage of hearing aid increases neural activity at the peripheral centres and inturn reduce unnecessary hyperactivity at higher centers leading to tinnitus relief
- Due to the altered neural activity at higher centers of auditory pathway, there is a decreased inhibition process. So stimulation by hearing aids may help the brain perform its inhibitory function in a better manner as the neural input at the peripheral levels is refined when there is adequate stimulation through hearing aid.
- Tinnitus is a pseudo –sound. Individuals are confused about its perception. When they are aided with hearing aids they would know the target signal is speech and they would attend to that rather than the pseudo sound (active segregation).
- Hearing aids amplify the background noise and in turn mask tinnitus.

- The listening stress and fatigue due to tinnitus is decreased with the use of hearing aids due to selective attention

2.6. Optimization of Hearing Aids for Tinnitus Relief

In addition to the usage of hearing aid, manipulation of certain characteristics in hearing aids helps in tinnitus relief. The fitting of open ear devices, usage of omnidirectional microphone, setting low compression knee-points, disabling digital noise reduction are a few methods through which tinnitus may be maximally suppressed (Bo and Ambrosetti, 2007).

2.6.1. Open fit hearing aids: Ganz, Elisabete, and Pedalini, (2007) compared the efficacy of vented ear moulds with pressure vented ear moulds. Pressure vented ear moulds was preferred by individuals with flat hearing loss, while vented ear moulds was preferred by those with sloping hearing loss. Overall the presence of vent in the ear mould led to the tinnitus relief as the low frequency information transfer especially at 500 Hz and 1000Hz through the mould was more. Also, in study by Parazzini, Del Bo, Jatreboff andTagnola (2014) compared the usage of hearing aid with an open ear mould and sound generator in 91 individuals with tinnitus. The effectiveness of tinnitus relief was monitored by administering THI every 3, 6 and 12 months. They concluded that tinnitus relief from hearing aid with open mould was at par with that of sound generators. Thus, open fit hearing aid naturally allow the low frequency sound to enter into ears and in addition, it amplifies low frequency ambient sound and attribute to tinnitus relief.

2.6.2. Digital hearing aids: An addition of certain manipulations in the hearing aids can lead to tinnitus relief. Such flexibility is available in the digital hearing aids. An analogue hearing aid is less flexible in terms of adapting it for the needs of the individual especially for those with tinnitus (Konig et al., 2006). Hence a digital hearing aid is preferred over an analogue hearing aid on tinnitus relief.

2.6.3. Bilateral hearing aids: For an individual with bilateral hearing loss, binaural stimulation through hearing aids is advantageous in various aspects. It is applicable for tinnitus relief too. A greater effect of relief of tinnitus is observed when the hearing aid was used binaurally. Out of 71 individuals with tinnitus 47 of them preferred binaural hearing aids while only 9 of them opted for monaural usage of hearing aid (Brooks and Hospital, 1981). Thus, the usage of bilateral hearing aids is advisable on tinnitus relief in whom ringing sensation is experienced in both ears.

2.6.4. Naïve hearing aid users: Zagólski (2006) reported that out of 33 older adults with tinnitus, 28 of them obtained immediate relief from tinnitus when they used it at the first instance. However after prolonged usage of hearing aids, 18 of them had complete relief. In yet another study by Surr, Montgomery, and Mueller, (1985) who concluded that out of 200 individuals with tinnitus who were surveyed about half of them reported relief from tinnitus when they started using hearing aid and they opined reduced severity of tinnitus from severe to partial after usage of hearing aid. Hearing aids were programmed based on the hearing loss and no additional modification was done. Naïve hearing aid users obtain tinnitus relief reflecting the quickness in masking of tinnitus by a hearing aid.

2.6.5. Digital noise reduction and Directionality: The presence of tinnitus exacerbates in silence. The relief of tinnitus occurs when the individuals are exposed to some amount of background environmental sounds. This happens when the directional sensitivity of the microphone of the hearing aid is omnidirectional. Individual with tinnitus can take maximum advantage of diffuse ambient noise for the masking of tinnitus through omnidirectional microphones. (Ricketts and Mueller, 2015) . In addition activation of digital noise reduction prevent the possibility of the ambient noise to be audible to the individuals with tinnitus, hence the possibility of ambient noise masking the tinnitus is ruled out. Hence digital noise reduction is recommended to be switched off for tinnitus relief (Ricketts and Mueller, 2015).

2.6.6. Compression knee point: Tinnitus relief can be obtained when it is generally masked by the environmental sounds. The environmental sounds can be made audible by setting the compression knee point low, which enables amplification of low intensity environmental sounds. Wise (2003) conducted a study wherein the compression threshold of 30 dB SPL and 50 dB SPL were compared to assess reduction of audibility of tinnitus. It was found that 30 dB SPL was better than 50 dB SPL for the reduction of audibility of tinnitus. The probable reason that can be speculated is that when the compression knee points are lower, the environmental noise and the ambient noise are amplified sufficiently louder than when the compression knee point was 50 dB SPL.

2.6.7. Prescriptive formula: Prescriptive procedures are a systematic and organized approach for hearing-aid fitting (Traynor, 1997). It was aimed to provide the most appropriate amplification based on a person’s hearing loss. Commonly used conventional prescriptive procedures for hearing-aid fitting includes the desired sensation level input/output [DSL (I/O)] (Cornelisse et al, 1995) and the National Acoustic Lab (NAL) (Byrne & Tonisson, 1976). Wise (2003) reported that 80 % of individuals with tinnitus experienced less audible tinnitus when hearing aids were programmed according to the DSL (I/O) v4.0 than NAL-NL1 prescription. A probable reason for this could be the fact that most noise is concentrated in the low frequency region (Moreland, 1988) and DSL (I/O) generally prescribes more gain at low frequency for low intensity sounds than NAL-NL1 (Dillion, 2001).

Shekhawat, Searchfield, Kobayashi, and Stinear, (2013) conducted a study on 25 individuals with tinnitus by comparing winner gain and gain prescribed by DSL (I/O) v5.0. The output of speech from hearing aid was obtained, its gain was varied from 1 dB to 6 dB in step of 1 dB and resultant gain is called winner gain. In general it was found that higher the tinnitus pitch, winner gain tended to match the output of DSL (I/O) v5. For low frequency tinnitus, winner gain was lower than DSL (I/O) v5 across all frequencies. The preferred gain setting for those with tinnitus pitch less than 4 kHz was 1 to 3 dB less in winner gain than DSL (I/O) v5.0 across entire frequency range. When the tinnitus pitch ranged from 4 kHz to 8 kHz, winner gain was found to be 2 dB less than DSL (I/O) v5.0 across the entire high frequency (2 kHz and above) but more than DSL(I/O) v5.0 at the low and mid frequency (from 0.25 to 1.5 kHz) was required for the relief of tinnitus. However this difference was minimal (less than 0.5 dB). For the tinnitus pitch at 8 kHz, the gain requirements for the relief of tinnitus was slightly more in winner gain than DSL(I/O) v5.0 at three frequencies (0.75, 1, and 6 kHz) and slightly less than DSL(I/O) v5.0 at the other frequencies measured. But, the difference was not more than 1 dB. The authors suggest that in individuals with tinnitus can start their treatment with DSL (I/O) and later tuning of gain as per their individual preference.

2.6.8. Hearing aid bandwidth: Schaette, König, Hornig, Gross, and Kempter, (2010**)** evaluated relief from tinnitus in two groups: one whose tinnitus pitch is less than 6 kHz and the other above 6 kHz. It was found out that after the usage of hearing aid for about two months, scores of self rated tinnitus loudness and tinnitus related distress scale decreased for the group whose tinnitus pitch is less than 6 kHz while such a result was not observed for the other group. Authors concluded that acoustic stimulation treatments against tinnitus could be most effective only when tinnitus pitch is within the stimulated frequency range through the hearing aid. In yet another study by Moffat (2009) who compared the tinnitus relief between two groups one with standard amplification regime and the other with high bandwidth amplification (from 250 to 8000Hz). Those individuals who were fitted with standard amplification regime experienced a significant improvement than compared to those with high bandwidth amplification. The probable reason for the absence of significant improvement was due to small changes in loudness within 10 dB which could not be depicted significantly.

Despite various studies on the effect of hearing aid on tinnitus relief, none of the studies have shed light on the importance of alteration of gain provided through the hearing aid at tinnitus pitch. In order to focus on this issue, a study was conducted by

Swathi et al. (2015). Out of 15 participants, for those individuals whose tinnitus pitch was above 5000Hz, tinnitus suppression was observed when the gain at the corresponding tinnitus pitch was increased. This explains the importance of manipulation of gain at tinnitus pitch for tinnitus relief. However, there is a methodology error in assessing tinnitus relief from gain set at tinnitus pitch. In their study only one program was utilized and assessed how much gain required for those individual who had low and high pitch tinnitus. But they have not compared between the gain prescribed for hearing loss and additional gain set at tinnitus. Thus, in the present study the gain set at three different programs was compared to investigate the best program that suppresses tinnitus without compromising speech perception.

Chapter 3

Method

A one shot test and randomized repeated measures with comparative and correlative research design was used to study the manipulation of gain in hearing aid on tinnitus relief.

3.1. Subject selection criteria

1. A total of twelve participants with age ranged 30-60 years (mean age= 50.08 years) having acquired bilateral mild to moderately severe sensorineural hearing impairment who have either bilateral or unilateral tonal tinnitus(tinnitus pitch ranging from 250 to 6000Hz) at the time of data collection were recruited for the study. Those participants who had normal middle ear status as indicated by 'A' type tympanogram with elevated or absent reflexes at frequencies from 250 Hz to 4 kHz (in octave) were considered.
2. Naïve hearing aid users were included in the study.
3. Perception of tinnitus should be present even after fitted with hearing aid
4. Participants were native speakers of Kannada and none of them have any complaint of neurological, psychological and cognitive problems.
5. Tinnitus Handicap Inventory was administered and based on the score (Table-1) obtained on it each participant was grouped either to mild group or severe group. The score of seven participants on THI were within mild range and the rest five participants were in the severe range.

Table 3.1: *Details of participants*

Age	Thresholds (HL)	Thresholds (SPL)	Tinnitus Pitch	MML	THI raw scores	THI Nominal
50	43.75	56.00	6000	78	18	Mild
50	43.75	56.00	4000	94	18	Mild
56	68.75	81.00	250	64	20	Mild
56	73.75	86.00	250	80	20	Mild
52	55.00	67.25	1500	52	22	Mild
58	67.75	79.75	6000	94	28	Mild
60	32.50	44.75	500	50	28	Mild
58	61.00	69.75	250	72	52	Severe
35	58.75	71.00	3000	57	64	Severe
33	62.50	74.75	3000	84	68	Severe
45	48.75	61.00	1500	80	68	Severe
48	68.75	81.00	250	58	76	Severe

MML: Minimal Masking Level; THI: Tinnitus Handicap Inventory

3.2. Test Environment

Tests were carried out in a sound treated double room situation. The noise levels at frequencies from 250 to 8 kHz were within the permissible limits as per ANSI (S3.1; 1991).

3.3. Instrumentation

The following instruments and speech materials were used.

1. A calibrated diagnostic two channel audiometer with head phones (TDH-39) was used to measure the hearing sensitivity, speech identification scores, and minimum masking level. Bone vibrator (B-71) was used to obtain bone conduction thresholds. Loud speaker was used to obtain SNR 50 and to present the sentences to rate the best amplification strategy on tinnitus relief.
2. Personal laptop was used to play the recorded standardized sentences to obtain SNR 50.
3. Sorino X Mini - Receiver in the canal (RIC) digital hearing aid was used, which has option to switch off directional microphone and deactivate digital noise reduction (DNR). In addition appropriate dome size was selected based on opening of ear canal of each participant.
4. Aux viewer software was used to prepare stimulus for SNR 50
5. Fonix 7000 hearing aid analyzer and winchap (v-3) were used to measure the gain and output of the hearing aid.

Speech materials

1. Phonemically balanced (PB) word lists in Kannada developed by Yathiraj and Vijayalakshmi (2005) was used, to obtain open set speech identification score.

2. A standardized three lists of Kannada sentences developed by Geetha, Sharath and Manjula (2013) were used to obtain SNR 50 from different programs and also to rate the best program in hearing aid which gives tinnitus relief.

3.4. Stimulus preparation for SNR 50

Speech shaped noise having spectrum similar to that of standardized sentence was prepared. The procedure of generating speech shaped noise is given elsewhere (Shetty and Mendhakar, 2015). Three lists of standardized Kannada sentence were used, which are phonetically and phonemically balanced. Each sentence in the list comprised of five target words. For each sentence, root mean square (RMS) was identified and then noise was added at desired SNR. The first list of ten sentences was mixed with speech shaped noise at different signal to noise ratios ranged from +12 dB to -6 dB SNR in 2 dB step size. The onset of noise was started 500 ms before the onset of each sentence and continued for 500 ms after the offset of the sentence. A smooth ramp (rise and fall time) was made to the noise using cosine function to avoid unintended effects. The following formula was used to add noise to each sentence. Similarly, to the other two lists of sentences noise was added at different SNR using similar procedure as specified earlier. Below mentioned code was used to generate desired SNR in Aux Viewer software.

$$\boldsymbol{SNR} = \mathbf{wave}(\text{filename})@\ \mathbf{rms}\ >> 500 + \ ramp\ (wave\ (\text{"}noise\text{"})@\ rms, 20)$$

3.5. Procedure

The following procedures were utilized for subject selection and to study the manipulation of gain in hearing aid on relief from tinnitus and speech perception.

3.5.1. Subject selection

1. The pure tone thresholds for air conduction at octave frequencies from 250 Hz to 8 kHz were obtained using +10 and -5 dB procedure as specified by Carhart & Jerger (1959). The bone conduction thresholds from 250 Hz to 4 kHz were identified using similar procedure.
2. One of the lists of phonetically balanced word list developed by Yathiraj and Vijayalakshmi (2005) was presented through headphones. Each participant was instructed to repeat the word heard. The number of correctly identified words were counted and converted into percentage.
3. Tympanometry was carried out using 226Hz probe frequency and pressure rate varied from 200/600 daPa. Ipsilateral and contralateral reflexes were found at 500 to 4 k Hz (in octave) by varying the intensity insteps of 5 dB to notice a minimum change in the compliance of tympanic membrane.
4. Administration of Tinnitus Handicap Inventory**:** Tinnitus Handicap Inventory (THI) is a quantitative measure which comprised of 25 questions (Newman et al. 1996). The standardized Kannada version of this test developed by Zacharia et al (2012) which was utilized to assess the degree of severity of tinnitus and its effect on the daily living and communication handicap. Each question was rated on a three point rating scale 'yes' as 4, 'sometimes' as 2, and 'no' as zero. The maximum score that can be obtained from this test battery is 100. The scoring pattern is 2-16 slight, 18-36 mild, 38-56 moderate, 58-76 severe and 78-100 catastrophic.

3.5.2. Tinnitus pitch: In order to obtain the tinnitus pitch, a standardized procedure by Henry et al. (2002) was adopted. The ear contralateral to the ear in which tinnitus was present was selected to deliver different tones of frequencies from 125 Hz to 8000 Hz in octaves mid octaves through headphones at the most comfortable level. Each participant was instructed to indicate if the pitch (frequency) of the tone presented and their perceived tinnitus pitch are same or different. If the participants could not exactly match the pitch, they were told to report the tone which was closest to their pitch of tinnitus. The pitch at which participant indicated it as same, or the nearest as that of their tinnitus was considered as the tinnitus pitch.

3.5.3. Tinnitus Minimum Masking Level: The procedure of tinnitus making level is adopted from the masking curve concept by Feldmann (1971). Each participant was instructed to pay attention to tinnitus and report minimum level at which tinnitus was masked by a narrow band noise. A narrowband noise was presented at threshold level through the headphones to the ear in which tinnitus was present. The level of it was increased in 1 dB step until the intensity of noise was just sufficient to mask the tinnitus. Likewise at different frequencies (250 Hz, 500 Hz, 750 Hz, 1000 Hz, 1500 Hz, 2000Hz, 3000Hz, 4000Hz, 6000 Hz, 8000 Hz) a minimum masking levels (MML) at which tinnitus was suppressed were measured. The procedure was carried out thrice for the consistency of results. A relative gain as a function of frequency was calculated by taking the difference between MML at each frequency and MML at tinnitus pitch.

3.5.4. Programming and recording the output of hearing aid at tinnitus pitch: Sorino X Mini RIC hearing aid was programmed using DSL i/p (v-5) in which appropriate gain was prescribed with respect to the participant's hearing loss. The option of directionality was disabled, noise reduction circuit was switched off and compression threshold was set at 30 dB SPL. To verify gain in hearing aid real ear insertion method was performed on each participant test ear (tinnitus ear). Each participant was seated at 12 inch distance from loudspeaker and positioned at 45^0 azimuth.

The probe tip detached from probe unit was marked 5 mm past the end of the doom of RIC hearing aid. Later the probe tip was attached to probe unit and inserted into the ear canal (tinnitus ear) till the marking of probe tube was visible at tragal notch. Winchamp (v3) software was loaded in the personal laptop which was connected to the Fonix 7000 hearing aid analyzer. The measurements were carried out through the software. The levelling was done once the probe tube was inserted into the ear canal. The real ear unaided response (REUR) was measured for digi speech at 65 dB SPL. The output SPL at the level of ear canal was measured at octave frequencies from 0.25 kHz to 8 kHz.

Further, without changing the position of probe tube at ear canal, the hearing aid programmed at 'prescribed' gain (P1) settings was fitted on subjects' ear. The real ear aided response (REAR) was measured (at octave frequencies from 0.25 kHz to 8 kHz) for the digi speech presented at 65 dB SPL. The Fonix 7000 hearing aid analyzer automatically calculates the real ear insertion gain (REIG) at octave frequencies from 0.25 kHz to 8 kHz by subtracting REAR from

REUR. It was ensured that REIG was almost matched to the prescriptive target by increasing the prescriptive gain in hearing aid. From the REIG curve the gain (in SPL) at the tinnitus pitch (P1) was noted down.

In addition, without changing a position of probe tube and hearing aid, second program was activated in the test hearing aid. In the second program gain level was set according to the preference of participant. The recorded Ling six sounds were used to set the gain at preferred level. These recorded Ling six sounds were presented at 65 dB SPL at random order. Each participant was instructed to judge the loudness and clarity of these sounds informally. Depending on the participant's response the gain with respect to the spectrum of each sound was programmed. From the REIG curve the gain (in SPL) at the tinnitus pitch (P2) was measured.

Further, third program was activated in the same hearing aid. In the third program, the gain in hearing aid at tinnitus pitch was varied systematically. Each participant was instructed to pay attention to the tinnitus and report level of hearing aid gain at which tinnitus was masked. To arrive at gain on tinnitus suppression the standardized sentences were presented at 65 dB SPL and the gain in hearing aid was systematically increased in 1 dB step size till the point where tinnitus was suppressed by the hearing aid. The minimum gain at which the participant reports suppression of tinnitus is defined as gain at tinnitus pitch. From the REIG curve the gain (in SPL) at the tinnitus pitch (P3) was measured.

Finally, gain at tinnitus pitch was calculated by subtracting the gain (in SPL) between programs (P1, P2 and P3) at tinnitus pitch. A total of two gain differences at tinnitus pitch were determined (i.e P3-P1and P3-P2).

3.5.5. SNR 50: Ten sentences embedded at different SNRs were randomized. Each sentence was presented at 65 dB SPL in aided condition. The participants were instructed to repeat the sentence heard. The SNR level at which the testing started (L) and number of correctly recognized target words in each sentence was noted down. The total number of target words from all sentences was added (T). Also, the total number of words per decrement (W) and SNR decrement step size in each sentence (d) were noted down. The obtained values were substituted to the given equation adapted by Spearman-Karber to determine SNR 50 % (Finney, 1952). The below equation was used to calculate the SNR 50. From each study participant the SNR 50 was obtained from all three programs of hearing aid.

$$50 \ \ \text{point} = L + (0.5 * d) - d\,(T)/\,W$$

3.5.6. Judgment of tinnitus relief from three programs in hearing aid using paired comparison: A paired comparison judgment was used to obtain the best program in hearing aid in which maximum relief was attained. A total of three comparisons (prescriptive gain, preferred gain and adjusted gain) were made per trial. Each participant was instructed to choose one program which gave tinnitus relief against other program by listening to a sentence presented at 65 dB SPL, delivered through loudspeaker. The best program was selected from a total of three comparisons which were presented in Round Robin Tournament format. A preference score of one mark was assigned for the best program. Likewise three trials were performed and it was ensured that three comparisons in each trial were randomized. Finally the number of times each program was selected on relief from tinnitus was noted down.

3.6. Statistical Analyses

1. Descriptive analyses was performed for the data of MML; preference percentage and gain difference.
2. Relationship between MML and gain at tinnitus pitch was determined using Spearman's product moment correlation.
3. In the next step, Friedmen's test was conducted to investigate difference in preference score. If significant difference was present, then Wilcoxon signed rand test was performed.
4. In the next step, Friedmen's test was performed to determine difference in SNR 50 between programs. Further Mann Whitney U test was conducted to see difference between groups on SNR 50.

Chapter 4

Results

The aim of the experiment was to investigate manipulation of gain in hearing aid on tinnitus relief and speech perception. The Minimum Masking Level (MML) required to suppress tinnitus were measured at different frequencies. Correlation between MML at tinnitus pitch and gain at tinnitus pitch was investigated. The analysis of the paired comparison was performed to check for the best program, which led to the relief from tinnitus. In addition, preference of hearing aid (in percentage) on tinnitus relief from study participants was documented. Further, a gain differences between programs at the tinnitus pitch were examined. The effect of manipulation of gain on speech perception was analyzed. These data were subjected to statistical analyses using the Statistical Package for Social Sciences (SPSS) software (version 17.0).

4.1. Minimum Masking Level

Figure 4.1 represents relative gain plotted as a function of frequency, in each participant of mild group. Each curve represents the amount of masking noise at different frequencies required to suppress tinnitus and this was descriptively analyzed. The black dotted circle indicates tinnitus pitch. From Figure 4.1 it can be observed that for low pitch tinnitus (250 Hz and 500 Hz) to be suppressed, more amount of masking noise was required above tinnitus pitch than at the pitch of tinnitus. In participants who had tinnitus at 1500 Hz; 4000 Hz; 3000 Hz and 6000 Hz frequency, a masking noise at below and above tinnitus pitch required more noise level than at tinnitus pitch. Further, it is also found that immediate adjacent frequencies (above and below) near tinnitus pitch required less noise level to suppress tinnitus. However, far frequencies with respect to tinnitus pitch required more level of noise to suppress tinnitus. Similar observations were found in severe group (Figure 4.2).

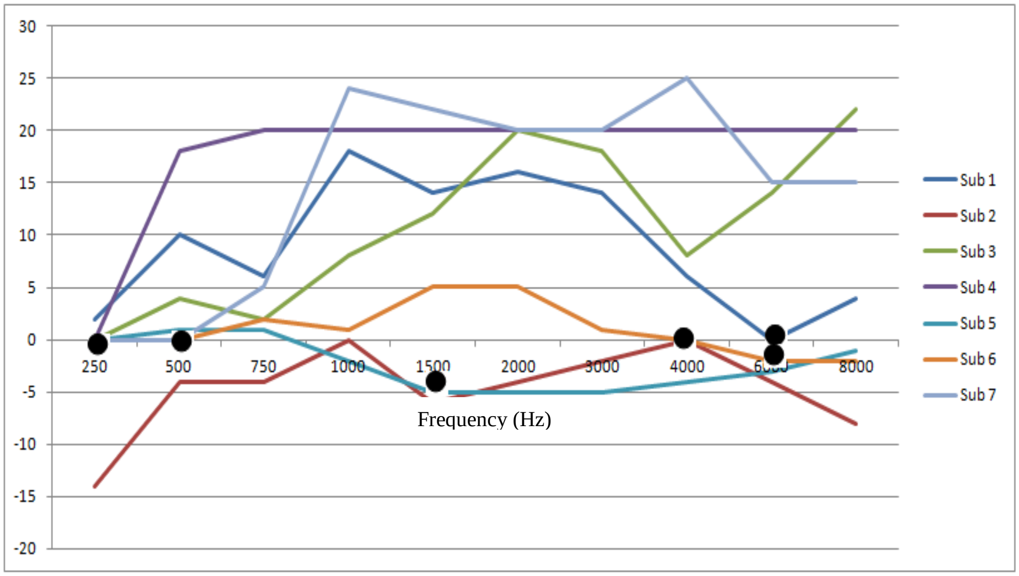

Figure 4.1: *The relative gain as a function of frequency for mild group*

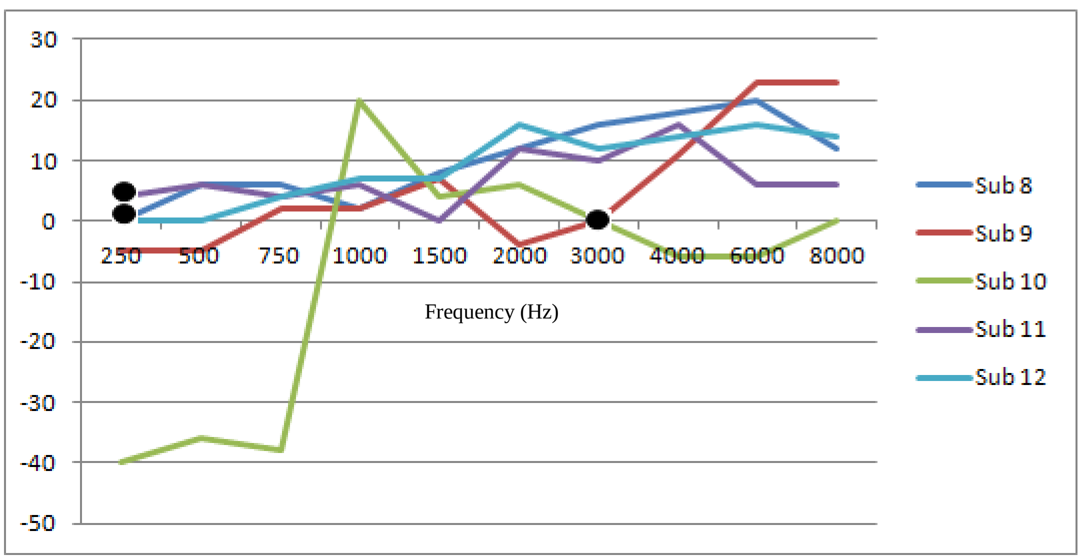

Figure 4.2: *The relative gain as a function of frequency for severe group*

4.2. Relation between MML at tinnitus pitch and gain at tinnitus pitch

The MML at the tinnitus pitch and the gain provided by the hearing aid at the tinnitus pitch in the three programs were subjected to Spearman's correlation. This was performed in each group. In mild group, result revealed no significant correlation between the MML at the tinnitus pitch and the gain provided by the hearing aid at the tinnitus pitch in P1 (N= 12, r_s= .24, p > .05); P2 (N= 12 r_s= .29, p > .05) and; P3 (N = 12 r_s= .28,p > .05).

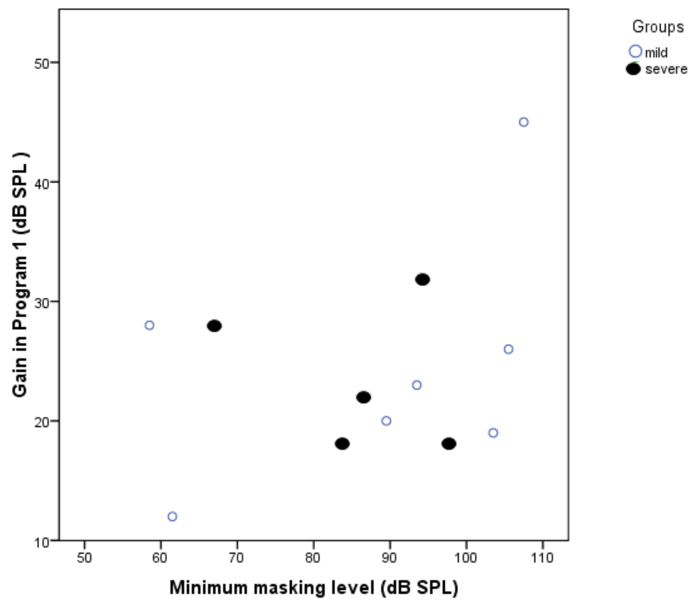

Figure 4.3: *Correlation between MML at tinnitus pitch and gain in P1 at tinnitus pitch.*

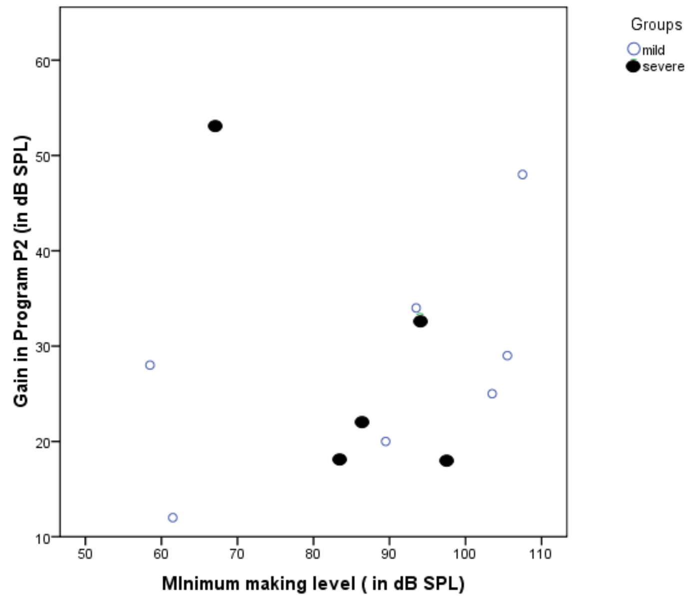

Figure 4.4: *Correlation between MML at tinnitus pitch and gain in P2 at tinnitus pitch*.

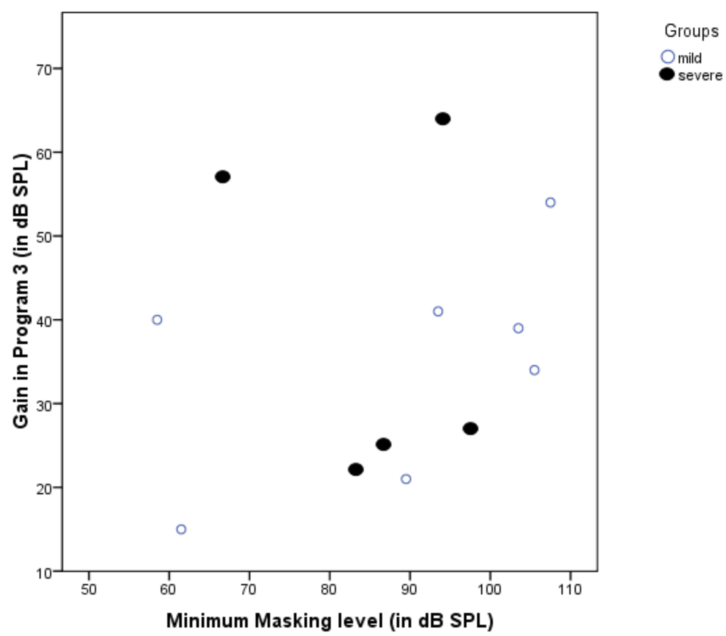

Figure 4.5: *Correlation between MML at tinnitus pitch and gain in P3 at tinnitus pitch.*

4.3 Paired Comparison

The preference scores obtained from three different programs using paired comparison were analyzed using Friedman test. The test was performed separately for the mild group and severe group. For the mild group, the results showed a significant effect of preference scores between programs on tinnitus relief [$\chi^2 (2) = 6.88$, $p < 0.05$]. Further, a Wilcoxon matched pairs signed rank test was conducted to determine which program has caused difference in the preference score on tinnitus relief in the mild group. Results of this analysis indicated that there was a significant difference in preference score between P1 and P3 ($z = -2.53$, $p < 0.05$) and; P2 and P3 ($z = -2.11$, $p < 0.05$) on tinnitus relief. However there was no significant difference in preference score between P1 and P2 programs on tinnitus relief ($z = -0.175$, $p > 0.05$). Whereas, in severe group, it was found that there was a significant difference in preference score between three programs on tinnitus relief [$\chi^2 (2) = 10.00$, $p < 0.05$]. Further in order to ascertain in which program might have caused significant preference on tinnitus relief, a Wilcoxon matched pairs signed rank test was conducted for the severe group. It was found that there was a significant difference in preference score between programs P1 and P2 ($z = -2.23$, $p < 0.05$); P2 and P3 ($z = -2.23$, $p < 0.05$); and P1and P3 ($z = -2.23$, $p < .05$) on tinnitus relief. The results indicate that P3 was the preferred program and received significantly more favorable ranking than P1 and P2 on tinnitus relief.

4.4. Preference Percentage

The round Robin tournament revealed the preference of the best program on tinnitus relief. In the mild group, 57.14% (4/7 participants) of the participants preferred gain at tinnitus pitch, 42.85(3/7 participants) of the participants opted for the preferred gain and none of them preferred the prescriptive gain. Whereas in severe group, 80% (4/5 participants) of the participants preferred gain at tinnitus pitch, 20% (1/5 participants) of the participants opted for the preferred gain and none of them preferred the prescriptive gain. Thus, in both the groups a majority of them preferred gain at tinnitus pitch to obtain maximum relief from tinnitus than the other programs.

4.5. Gain Difference

The gain differences between programs at the tinnitus pitch were obtained in each group. From Table 1, it was observed that more gain was required in P1 and P2 than P3 to suppress tinnitus. For the mild group, a gain of 10 dB more was required in P1 to suppress tinnitus than P3. In addition, a gain of 6.4 dB more was required in P2 to suppress tinnitus than P3. For the severe group, a gain of 15.6 dB more was required in P1 to suppress tinnitus than P3. In addition, a gain of 10.4 dB more is required in P2 to suppress tinnitus than P3.

Table 4.1: *Gain difference between programs in each group*

Group		P3-P1	P3-P2
Mild	Mean	10.14	6.42
	SD	7.104	4.79
Severe	Mean	15.60	10.40
	SD	14.25	11.73

4.6. SNR 50

The SNR 50 was obtained from each program from the participants of each group. These data was subjected to a Friedman test to evaluate differences in SNR 50 between prescriptive gain (Mean =4.28, SD =4.08), preferred gain (Mean =3.21, SD=2.65) and gain at tinnitus pitch (Mean =3.50, SD=2.54). The test result revealed that there was no statistically significant [χ^2 (2) = 1.14, $p > 0.05$] between programs on SNR 50. In severe group, the SNR 50 obtained from prescriptive gain was Mean= 6.50 with SD= 4.06; preferred gain was Mean=5.60 with SD= 3.71; and gain at tinnitus pitch was Mean=4.50 with SD=3.62. The data of SNR 50 from three programs were subjected to Friedman test. It revealed that there was no statistically significant [χ^2 (2) = 4.10, $p >0.05$] between program on SNR 50. It infers that SNR 50 was similar for all three programs. This was true for each group.

Further, to ascertain if there was any significant difference between groups on SNR 50, a Mann -Whitney U test was performed. It was found that there was no significant difference (U = 136.00, z = - 0.69) between mild (mean=3.66, SD= 3.04) and severe (mean=5.53, SD= 3.62) groups on SNR 50.

Chapter 5

Discussion

The aim of the study was to determine the best gain setting in hearing aid on tinnitus relief. From the study participants of each group minimum masking level (MML) was obtained to document tinnitus suppression in them. Irrespective of group, if a tinnitus was at high pitch, more level of noise was required at low and high frequencies than noise level at tinnitus pitch to mask the tinnitus (Penner, 2016). Conversely, tinnitus at low pitch required more level of high frequency noise than at tinnitus pitch to mask the tinnitus (Zwicker, 1974). Tinnitus, at mid pitch, required a relatively lesser amount of low frequency noise than high frequency to suppress tinnitus. The outcome of the MML result on tinnitus suppression can be explained by psychophysical tuning curve and hearing loss associated with them.

At high pitch tinnitus, basal part of cochlea excites even in absence of stimulation (phantom perception). For it to be suppressed, low frequency noise level required was way high. This is because all the participants had minimal to mild hearing loss at low frequency region and it generally stimulates at apical region of cochlea required more level of noise to just mask the tinnitus at high pitch, which excites at basal part of cochlea. In addition, high frequency stimulation above high-pitched tinnitus required high level of noise for it to mask. This could be attributed to more number of outer hair cells damage and consequent loosening of basilar membrane stiffness at basal part of cochlea, which reflected in high frequency hearing loss. Further, high frequency stimulation above high pitch tinnitus excites at basal turn and required high level of noise to suppress tinnitus.

At low pitch tinnitus, apical part of cochlea excites in the absence of stimulation. It was found that higher level of masking noise at high frequency was required for it to suppress than at tinnitus pitch. The reason could be loss at high frequencies and presentation of high frequency noise level excites basal turn of cochlea would requires more level of noise to suppress low pitch tinnitus which excites at apical region of cochlea. However, tinnitus suppression at mid pitch required higher amount of noise at high frequency than at low frequency. This is because poorer threshold at high frequency exits at basal turn of cochlea required more level for it to suppress the tinnitus, which excites at middle portion of cochlear turn.

Masking of tinnitus by a narrow band signal was helpful in judging the level of signal frequency masks their perceived tinnitus. This can act as a good indicator that when the incoming signal is loud enough can lead to tinnitus masking and eventually relief can be seen in them. Intervention with hearing aid serves two purposes. It alleviates hearing loss by appropriate gain and eventually masks the audible tinnitus. Thus, in the present study gain setting in hearing aid was experimentally altered to see in which program participants have got maximum benefit. In the first program the gain was set according to the hearing loss, which was prescribed by prescriptive formula. In another setting where the gain was altered depending on subjective preference by listening through Ling six sounds. With these two programs in hearing aid subject reports a tinnitus perception. This could be because the participants from each group were unable to segregate tinnitus from sentence perception, even though the instruction given to them to ignore tinnitus. This suggests there would be stronger connection between source generator at different parts of auditory structure and brain on tinnitus percept. Thus, hearing aid at these gain settings showed less benefit in ignoring the tinnitus. The results of the study is in consonance with the research report of Moore (1982) who demonstrated a separation into attended and unattended streams termed as the figure ground phenomenon can be one of the contributing factor for tinnitus relief.

It was evident that loudness of the tinnitus would be more than 5 to 10 dB above threshold (Goodwin & Johnson, 2016). After treating audibility with hearing aid, a gain at tinnitus pitch was linearly increased in step of 1 dB until participants report tinnitus suppression. It was observed that, irrespective of group, gain difference between preferred; prescriptive gain setting and gain at tinnitus pitch ranged from 6 to 10 dB and 10 to 15 dB, respectively. This indicates a gain set at tinnitus pitch was approximately matched or well above the loudness of tinnitus. Threshold of audibility was alleviated by prescriptive formula and addition gain at tinnitus pitch suppresses tinnitus. Thus, gain set at tinnitus pitch reported positive outcome. This is because amplified frequency response of sentence at tinnitus pitch masks the tinnitus effectively.

It was found that, there was no correlation between MML at the tinnitus pitch and the gain at the tinnitus pitch. This clearly indicates that the loudness of tinnitus and the amount of gain required to obtain tinnitus relief are not directly linked. This is because tinnitus loudness is independent irrespective of hearing loss. However, gain in hearing aid is dependent on degree of hearing loss. These discrepancies perhaps have caused no relation between tinnitus loudness and gain set in hearing aid at tinnitus pitch on tinnitus relief. The result of present study concur with the research report of Tyler and Conrad-Armes (2016) who reports pattern of noise growth in sensorineural hearing loss is not well understood. However, in paired comparison the study participants' of mild [57.14%

(4/7 participants)]; and severe [80 % (4/5 participants)] group have showed significant preference of program three on tinnitus suppression. The gain setting in program three could have caused effective masking on tinnitus suppression. The study is in consonance with previous study by Swathi et al. (2015) who reported that increasing gain at tinnitus pitch was effective to cause tinnitus suppression especially when the tinnitus pitch is above 5 kHz.

The primary purpose of hearing aid was actually prescribed to alleviate hearing loss and improve speech perception. With gain adjustment at tinnitus pitch hearing aid should not compromise the primary purpose of improving speech perception. Thus, in the present study SNR 50 was compared between three programs. Results revealed SNR 50 remained unaffected with gain set at tinnitus pitch from other gain settings of preferred and prescriptive methods.

To conclude, minimal masking level at tinnitus pitch approximately guides clinician to set the gain at tinnitus pitch. The positive finding of program three on tinnitus relief shed light in setting gain at tinnitus pitch. In addition, primary concern of hearing aid on speech perception is not compromised in setting gain at tinnitus pitch. Thus, null hypothesis is rejected and the present study highlights a gain setting at tinnitus pitch as per individual requirement can tackle both hearing loss and associated tinnitus without affecting speech perception.

Chapter 6

Summary and Conclusion

Hearing aid is one of rehabilitative options available for tinnitus management. However, the focus on prescribing gain at tinnitus pitch is very limited. With this thought, the aim of the study was to determine if gain in hearing aid was changed at tinnitus pitch led to tinnitus relief without compromising speech perception. Thus in the present study, twelve subjects were recruited and grouped into mild (7) and severe (5) based on THI. All the participants were fitted with a hearing aid and three programs were set namely prescriptive, preferred and adjusted gain. A paired comparison method was performed to select the best program in suppressing tinnitus. In addition SNR 50 was also obtained from each program. It was found that a majority of the participants preferred increased gain at tinnitus pitch in comparison to the other programs. The participants of 'mild' and 'severe' groups required about 6-10 dB and 10 -15 dB increase in gain for tinnitus relief, respectively. This is because after amplification frequency response of sentence at tinnitus pitch masks the tinnitus effectively. In addition there was no difference between the SNR 50 scores in the three gain settings. It infers that hearing aid masks the tinnitus effectively when its gain is set at tinnitus pitch without compromising speech perception.

Clinical implications:

One program is sufficient to manage both hearing loss and tinnitus. As the results of the present study infers that gain set at tinnitus after alleviating hearing loss by prescriptive formula provides tinnitus relief without compromising speech perception.

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