EFFECT OF TINNITUS ON SPEECH PERCEPTION IN NOISE, TEMPORAL PERCEPTION AND AUDITORY WORKING MEMORY IN INDIVIDUALS WITH NORMAL HEARING SENSITIVITY

Jitesh Prasad Sahoo

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University of Mysore, Mysore

ALL INDIA INSTITUTE OF SPEECH AND HEARING

MANASAGANGOTHRI, MYSORE-570006

MAY, 2014

CERTIFICATE

This is to certify that this dissertation entitled **"EFFECT OF TINNITUS ON SPEECH PERCEPTION IN NOISE, TEMPORAL PERCEPTION AND AUDITORY WORKING MEMORY IN INDIVIDUALS WITH NORMAL HEARING SENSITIVITY"** is the bona fide work submitted in part fulfilment for the degree of Master of Science (Audiology) student with Registration Number 12AUD010. This has been carried out under the guidance of a faculty of this institution and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Dr. S. R. Savithri

Director

All India Institute of Speech and Hearing

Manasagangothri, Mysore -570006

Mysore

May, 2014

CERTIFICATE

This is to certify that this dissertation entitled **"EFFECT OF TINNITUS ON SPEECH PERCEPTION IN NOISE, TEMPORAL PERCEPTION AND AUDITORY WORKING MEMORY IN INDIVIDUALS WITH NORMAL HEARING SENSITIVITY"** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mrs. Chandni Jain

Guide

Lecturer in Audiology

Department of Audiology

All India Institute of Speech and Hearing

Manasagangothri, Mysore -570006

Mysore

May, 2014

DECLARATION

This dissertation entitled **"EFFECT OF TINNITUS ON SPEECH PERCEPTION IN NOISE, TEMPORAL PERCEPTION AND AUDITORY WORKING MEMORY IN INDIVIDUALS WITH NORMAL HEARING SENSITIVITY"** is the result of my own study under the guidance of Mrs. Chandni Jain, Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore; and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore Register Number: 12AUDIO010

May, 2014

Dedicated to Bapa & Bou

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Chapter 1

Introduction

Tinnitus is a word that derives from the Latin word "*tinnire*", which means "to make a buzzing sound. "It is defined as the conscious experience of sound that originates in the head" (McFadden, 1982). Another common definition of Tinnitus was proposed by the American National Standards Institute (ANSI, 1969) as "the sensation of sound without external stimulation". The occurrence of persistent spontaneous tinnitus in the adult population is 10.1 % and 5% of them explain their tinnitus as moderately or severely annoying and 0.5 % reports that it had a severe effect on their ability to lead a normal life (Coles,1984).

The presence of a hearing loss boosts the probability of an individual experiencing tinnitus and previous noise exposure is also a good predictor of tinnitus (Davis, 1995). Studies have also shown that hyperacusis co-occurs in patients with tinnitus (Anari, Axelsson, Eliasson & Magnusson, 1999; Beatnik, Fabijanska & Rogowski, 1999; Jastreboff & Jastreboff, 2000; Sood & Coles, 1988). Continuous exposure to noise can elicit tinnitus and apart from this, allergies, diabetes, high blood pressure, high cholesterol, earwax, tumors, Meniere's disease, medications (like aspirin) and ageing might also cause tinnitus. Tinnitus can be treated sometimes, if it is caused due to earwax, high cholesterol or tumor. If these conditions are treated, then tinnitus may also subside.

Tinnitus is usually subjective and is not perceived by anyone apart from the patient. Tinnitus in some cases such as pulsatile tinnitus or the tinnitus due to myoclonus of the palatal muscles may be heard by others and are called as objective tinnitus. Syndromic tinnitus is related with specific diseases such as Otosclerosis, Meniere's disease or Vestibular schwannoma (Mcferran & Phillips, 2007).

The perception of tinnitus varies from individual to individual. Some of them describe tinnitus as loud and intense, which may lead to psychosocial disorders and thus can affect their quality of life. Studies have also shown that the restrictions caused by tinnitus are linked to psychological factors, like mood swings, irritability and psychiatric diseases. Chronic tinnitus can be accompanied by depression (Holgers, Erlandsson & Barrenas, 2000; Folmer, Griest, & Martin, 2001), anxiety (Folmer, Griest, & Martin, 2001), insomnia (Folmer, Griest, & Martin, 2001), problems with auditory perception (Tyler & Baker, 1983; Hallam, Jakes & Hinchcliffe, 1988), and reduced general and mental health. In severe cases, intractable tinnitus may lead to suicide (Johnston & Walker, 1996).

Need of the study

Tinnitus is an otologic symptom and requires detailed audiological evaluation due to its numerous etiological conditions (Lockwood, Salvi, Burkard, 2002; Onishi, Fukuda, Suzuki, 2004). The existence of tinnitus could be due to the disorder in the neural activity at the level of the auditory system. Tinnitus of cochlear origin, even when undiagnosed by pure tone audiometry, may instigate a series of processes in the nervous system that may cause tinnitus (Bartels, Staal, Albers, 2007; Eggermont, 2004). Oxenham and Bacon (2003) reported that even a minute cochlear disorder may affect the cochlear amplification mechanisms.

Thus, tinnitus of cochlear origin might involve deformities of both cochlear function and the processing of tinnitus within the nervous system. Studies have shown that tinnitus impairs speech perception in noise (Newman, Wharton, Shivapuja, & Jacobson, 1994; Chen et al., 2006;

Hennig,Costa,Urnau,Becker & Schuster, 2011; Killion, 2002 and Ryu, Ahn, Lim, Joo, & Chung, 2012), temporal perception (Acraine & Pereira 2010; Gilani et al., 2013; Haas et al., 2012), cognitive efficiency (Hallam, McKenna & Shurlock, 2004; Susan, Catherine & Gary, 2006).

Perception of temporal abilities involves resolving the fine details in spectrum and temporal envelope of speech signal (Moore, 2003; Summerfield, 1987). The temporal resolution, which is a parameter of temporal processing, refers to the skill to identify changes in auditory stimuli over time. It plays an important role in understanding speech in noisy situations (Dubno, Horwitz & Ahlstrom, 2003; Oxenham & Bacon, 2003; Peters, Moore & Baer, 1998). Studies have investigated temporal perception in individuals with tinnitus and normal hearing to find out the possible effect of subtle cochlear changes in the auditory perception (Sanchez, & Carvallo, 2010). Results have shown that temporal perception and speech perception in noise is impaired in individuals with tinnitus.

Tinnitus also results in concentration difficulties which is a common complaint of individuals with tinnitus (e.g., Hallam, Jakes, & Hinchcliffe, 1988; Tyler & Baker, 1983). This could be because tinnitus might disrupt the processing of other information which is mediated by the working memory system. Working memory is an aspect of a cognitive system that allows us to sustain and manipulate information in mind for small periods of time. It involves tasks in which participants segregate their attention between on-going process and the short-term storage (Baddeley & Hitch, 1974; Daneman & Carpenter 1980). However, cognitive efficiencies in individuals with tinnitus in previous studies have been assessed through attention task, but auditory working memory has not been assessed in any of these studies.

Thus, separate studies have been conducted to investigate the impact of tinnitus on each of these parameters such as, temporal characteristics, speech perception in noise and cognitive performance. Thus, this study incorporates investigating the impact of tinnitus on all of these abilities in a single individual with tinnitus. This study is also designed to establish a relationship between auditory working memory, performance in temporal processing, speech perception in noise, if any and comparing it with the normal hearing individuals without tinnitus. It will help in understanding the way in which chronic tinnitus disrupts cognitive performance, normal temporal characteristics as well as speech perception ability in noise of the auditory system.

Aim of the Study

The present study aims to investigate the effect of tinnitus on the temporal characteristics of the auditory system, speech perception in noise, and auditory working memory in individuals with normal hearing sensitivity.

Objectives of the study

The objectives of the study are as follows;

1. To compare gap detection thresholds in white noise (GDT) and modulation detection thresholds (MDT) in individuals with tinnitus having normal hearing sensitivity to those without tinnitus.

2. To compare speech perception in noise (SPIN) in individuals with tinnitus having normal hearing sensitivity to those without tinnitus.

3. To compare auditory working memory in individuals with tinnitus having normal hearing sensitivity to those without tinnitus.

4. To assess the relationship between GDT, MDT, SPIN scores and auditory working memory, if any, in individuals with tinnitus having normal hearing sensitivity to those without tinnitus.

Hypothesis

The null hypothesis was assumed for the present study indicating:

1. There is no significant difference on GDT and MDT among individuals with tinnitus having normal hearing sensitivity to those without tinnitus.

2. There is no significant difference on speech perception in noise among individuals with tinnitus having normal hearing sensitivity to those without tinnitus.

3. There is no significant difference on auditory working memory among individuals with tinnitus having normal hearing sensitivity to those without tinnitus.

4. There is no significant difference among working memory, speech perception in noise and temporal resolution abilities among individuals with tinnitus having normal hearing sensitivity to those without tinnitus.

Chapter 2

Review of Literature

Tinnitus is defined as the perception of sound in the ears or head that lacks an external acoustic source (Jastreboff, 1993). Some authors have specified that tinnitus must exceed at least 5-min duration (Hazell, 1995). Dauman and Tyler (1992) proposed that pathologic tinnitus is head noise lasting at least for 5-min that occurs more than once per week.

Incidence of tinnitus

There are only a few studies available on the incidence of tinnitus. Axelsson and Ringdahl (1989) reported that 14.2% people among randomly selected population complained of tinnitus often or always while 2% of them had severe tinnitus.

Prevalence of tinnitus

Tinnitus is common in all age groups, however, studies have shown that there is either an increase in prevalence with age or tinnitus annoyance increases with age. Tinnitus is not rare during childhood: up to the age of 16 years, it ranges from 13 to 29% in children with normal hearing function and is 59% in children with hearing loss. The presence of tinnitus progressively increases with increasing age (Meric, Gartner, Collet & Chery-Croze, 1998). Hoffman and Reed (2004) in their review of six studies found a trend where, higher age decades showed a greater prevalence and a plateau in tinnitus prevalence was reached in either the 60–69 years or the 70–79 years age ranges. Tinnitus is also more frequently seen in males than in females (Axelsson & Ringdahl, 1989). Tinnitus is a lot more common in the left than in right ear (Axelsson & Ringdahl, 1989) and is more common in people with hearing loss than in normal hearing people (Axelsson & Ringdahl, 1989; Davis, 1995).

Types of tinnitus

Instead of conventional classification of tinnitus into objective and subjective tinnitus, Zenner (1998) proposed a tinnitus classification system which depicts the individual functional and anatomical steps involved in sound processing, with the middle ear, inner ear and brain. He classified subjective tinnitus into conductive tinnitus, sensorineural tinnitus and central tinnitus. Conductive tinnitus originates due to dysfunction in outer and middle ear, sensorineural tinnitus originates due to the dysfunctions in Outer Hair Cells (OHCs), Inner Hair Cells (IHCs), auditory nerve and the extrasensory elements like stria vascularis and central tinnitus arises in the brain.

Causes of tinnitus

Tinnitus is assumed to be the consequence of a lesion or dysfunction at any level of the auditory system. The association between high frequency hearing loss and tinnitus might be taken as support for a cochlear origin for tinnitus. Tinnitus can also exist in the presence of a perfectly functioning auditory periphery. But most modern research highlights the importance of central auditory pathways in both the development and maintenance of distressing tinnitus (Baguley, 2002).

The Neuro physiological model still remains the most accepted model to explain the cause of tinnitus (Jastreboff, 1995). It states that damage to peripheral organs act as triggers of tinnitus, and is supported by events that occur in the central auditory pathway, such as maladaptive neuroplastic processes and phenomena such as hyperactivity of the auditory cortex.

Characteristics of tinnitus

Meikle et al. (2004) reported that the onset of tinnitus is more often ‘‘gradual’’than “sudden”.The majority of subjects report that their tinnitus is heard like ‘ringing’ or a ‘clear tone,’ while only 3% describe their tinnitus to be heasrd as a ‘hum’, ‘clicking’, ‘roaring,’ or ‘pulse’(Lockwood, Salvi & Burkard, 2003; Meikle et al., 2004). The majority of tinnitus patients encounter the problem of sleep disturbance (Axelsson & Ringdahl, 1989; Jakes et al., 1985; Tyler & Baker, 1983).

Assessment of tinnitus

Medical Evaluation

The medical examination is especially important for patients with pulsatile tinnitus, which often has a certain physical pathology (Sismanis, 1998; Wackym & Friedland, 2004). A radiologic and/or laboratory testing in tinnitus patients can be recommended to determine if there is a reasonable possibility that there is a correctable cause for the tinnitus (Perry & Gantz, 2000; Wackym & Friedland, 2004).

Audiological Evaluation

Audiological evaluation should incorporate pure-tone audiometry, speech-recognition thresholds, speech identification scores, immittance evaluation & tinnitus psychoacoustic measures. Loudness discomfort levels (LDLs) should also be determined at audiometric frequencies to make sure that patients are not exposed to any sound during testing that can exceed their LDLs.

Tinnitus Psychoacoustic Assessment

Tinnitus psychoacoustic evaluation often involves finding the best matched frequency and intensity of the tinnitus perceived and whether residual inhibition (temporary suppression or elimination of tinnitus following auditory stimulation) exists. After obtaining the pure-tone audiogram, examiner focuses on finding a pitch match and a loudness match of the tinnitus perceived. Tinnitus psychoacoustic evaluation is necessary to assess or document the effects of masking stimuli on the tinnitus perception (Henry & Meikle, 2000; Schechter & Henry, 2002). These measures are also important for individualized counseling purposes, particularly in treatments like Tinnitus Retraining Therapy (TRT) (Jastreboff, 1995). Moreover, psychoacoustic measures are valuable in assessing and confirming the patient's subjective reports of his/her tinnitus state when the patent is involved in legal action related to the tinnitus (Henry, 2004).

A protocol for loudness and pitch matching was described in detail by Vernon and Meikle (1981). Their protocol involved three separate procedures that are alternated systematically among threshold testing, loudness matching, and pitch matching.

Questionnaires to assess severity of tinnitus

Questionnaires can be used to assess severity of tinnitus & most tinnitus questionnaires offer an index score to quantify the affect of tinnitus on the patient's day to day life (Meikle, Griest, Stewart, & Press, 1995). Some tinnitus instruments indicate different ranges of their index scores to be able to categorize tinnitus severity (Newman, Sandridge, & Jacobson, 1998). Although an index score is usually helpful in establishing the need for management, it can over- or under-estimate tinnitus severity. Some of the questionnaires which are used for tinnitus evaluation includes; Tinnitus Severity Index (TSI), Tinnitus Handicap Inventory (THI).

The TSI is a twelve-item questionnaire that measures the effect of tinnitus on work and social activity and on the overall quality of life with a 3-5 rating scale. The THI is a twenty-item self-assessment questionnaire where patient has to respond either "yes," "sometimes," or "no" to indicate the affect of tinnitus on emotions and daily activities. Responses are scored on a 4-2-0 scale, respectively; thus THI scores can range from 0-100. Higher scores in THI indicates greater perceived tinnitus handicap.

Tinnitus and Temporal processing

Temporal processing is an important auditory skill that is necessary for the complex auditory task necessary for higher level auditory processing. Temporal processing in the auditory domain refers to the processing of timing aspects and can involve majorly assessment of temporal resolution, temporal modulation transfer function. There are very less studies which aim to analyze the influence of the combined effect of hearing loss(basically a cochlear damage) and tinnitus on temporal auditory resolution. The hypothesis of these studies is that subtle cochlear disorder, in patients with tinnitus, reduces cochlear nonlinearity, thereby affecting auditory temporal processing.

Sanches, Sanchez, & Carvallo (2010) investigated extended high-frequency thresholds and the Gaps-in-Noise test (GIN) in 20 individuals with tinnitus. They reported that the correlation between GIN threshold and the high-frequency hearing threshold was statistically significant. They concluded that subtle peripheral hearing impairment affects temporal resolution in tinnitus, even when pure-tone thresholds shows normal hearing.

Sanches, Samelli, Nishiyama, Sanchez, & Carvallo (2010) compared the results of the GIN test in normal listeners with and without tinnitus. They reported in their study that individuals with tinnitus detected silence gaps with larger time of interval than the non-tinnitus individuals; i.e. poor temporal processing in tinnitus population. They attributed this result to the subtle cochlear damage in individuals with tinnitus having normal hearing sensitivity

Similar results was obtained by Gilani et al. (2013) in which they studied 20 subjects with tinnitus and reported that patients with tinnitus have temporal resolution difficulties in the Gap in Noise test, in spite of normal auditory thresholds. In another study by Haas et al. (2012), they reported poorer temporal acuity on gap detection threshold test in nine tinnitus patients than in non-tinnitus individuals with normal hearing sensitivity. However, Acrani and Pereira (2010) in their study of 15 individuals with constant bilateral tinnitus and normal hearing reported that there was no significant difference in temporal resolution of individuals with and without tinnitus.

Temporal auditory processing requisites the fine processing of temporal structures of sound and is dependent on the integral auditory system for perfect transmission of acoustical information through the auditory pathway. Majority of the studies have assessed a gap detection task and found a poor performance, which can be attributed to lesions in the external or internal cilia or the auditory tract, altered spontaneous activities of the auditory system in tinnitus subjects.

Tinnitus and Speech Perception

Speech perception abilities in quiet and noise have been assessed in individuals with tinnitus, with or without hearing loss to find whether tinnitus contributes to the commonly reported speech understanding breakdowns. Performance on speech recognition in quiet task cannot predict the recognition performance of an individual on a speech in noise task (Killion, 2002). Individuals with severe cochlear or neural disorders may show decrements on speech in quiet measures; however, older individuals with hearing loss or younger, individuals with mild processing disorders frequently demonstrate normal word recognition performance until a competitor is introduced into the task. Thus, the ability of an individual to recognize speech in the presence of background noise must be directly measured (Killion, 2002).

Newman, Wharton, Shivapuja and Jacobson (1994) investigated the relationship among psychoacoustic judgments, speech understanding ability and self-perceived handicap in subjects with tinnitus and hearing impairment. Audiometric speech measures were obtained for open set PAL=50 PB-words in a quiet, closed set synthetic sentence identification, speech perception in noise and dichotic sentence identification. They reported in their results that tinnitus may interfere with the perception of speech signals which have reduced linguistic redundancy.

Huang et al. (2007) conducted Mandarin Speech Perception in Noise Test (MSPIN) on 20 individuals with normal hearing sensitivity and tinnitus. They reported significantly lower MSPIN score in their clinical group compared to the control group. In another study by Ryu et al. (2012), they reported that tinnitus itself could adversely affect the speech perception ability.

Hennig,Costa,Urnau,Becker and Schuster, (2011) evaluated speech recognition in the presence of competitive noise in normal hearing individuals with tinnitus and hyperacusis. The results showed a similar performance in the speech recognition in silence, but a lower level performance on speech perception in noise in tinnitus patients when compared with normal-hearing individuals without complaints of tinnitus and hyperacusis.

Soalheiro et al. (2012) studied speech recognition index in factory workers with tinnitus who were exposed to environmental or occupational noise without the presence of competing noise. Among all the subjects with tinnitus, 50.4% classified their tinnitus as mild, 23% as moderate, 22.4% as intense, 2.0% said it was heard in the presence of silence, for 0.4%, tinnitus was heard after the workday, and 1.8% of people said it was unspecified. Among 359 workers with hearing loss with tinnitus and occupational noise exposure symptoms, 51.5% found difficulties in speech perception. Among workers with normal hearing sensitivity who reported occupational noise exposure and tinnitus, 83.1% of them reported problems in sound localization, speech perception, and the occurrence of one or more non-auditory symptoms like tachycardia, insomnia, anxiety, irritation and difficulties in concentration and attention.

Thus, the majority of the studies cited in the literature reported poorer speech perception abilities in individuals with tinnitus. The underlying basis for such complaints may be related to the interference to speech signals caused by the tinnitus, hearing loss which restricts the spectrum of sound available for higher level interpretation or a combination of the above two.

Tinnitus and Cognition

Cognitive mechanisms involved in the perception of tinnitus has been studied in the past. It has been noted that tinnitus is associated with reduced cognitive function (Wilson, Henry, Bowen & Haralambous, 1991), and some experimental research have confirmed effects of tinnitus on aspects of selective or divided attention and on working or long-term memory (e.g. Andersson, Erickson, Lundh & Lyttkens, 2000; Andersson, Ingerholt & Jansson, 2003;Andersson, Khakpoor & Lytkkens, 2002; Hallam, McKenna & Shurlock, 2004).

Andersson et al. (2000) investigated cognitive interference caused by tinnitus by means of a modified version of the Stroop color-word test. They concluded that tinnitus patients have impaired cognitive performance overall, as measured by these variations of the Stroop paradigm But, in their study they hypothesized that the result could have also been affected by hearing impairment.

Susan, Catherine and Gary (2006) tested 19 participants with normal hearing sensitivity and chronic, moderate tinnitus on auditory verbal working-memory and visual divided-attention tasks, with task order counterbalanced across participants. They reported that tinnitus affects cognition to the extent that it reduces cognitive capacity needed to perform tasks that require voluntary, conscious, effortful, and strategic control some. Hallam, Jakes and Hinchcliffe (1988) reported in their study that individuals with tinnitus had difficulties concentrating on the task and/or reduced capacity to store and retrieve information from working memory.

Acrani and Pereira (2010) assessed selective attention through the dichotic digit test (for figure-background) and speech in noise test (auditory closure) and found no significant difference in scores between tinnitus and non-tinnitus individuals. However, Husain et al. (2011) investigated auditory perception (passive listening and active discrimination) and cognitive processing in individuals with chronic tinnitus with hearing loss using functional magnetic resonance imaging. They reported that a differential engagement of a putative auditory attention and short-term memory, network comprising regions in the frontal, parietal and temporal cortices and the anterior cingulated may represent a key difference in the neural bases of chronic tinnitus accompanied by hearing loss relative to hearing loss alone.

Thus, it can be concluded that tinnitus disturbs the performance on the cognitive task or it might be the other way around; i.e. performing a demanding cognitive task draws attention away from the tinnitus. Literature suggests that tinnitus is likely to disrupt cognitive functioning and there are some indications that tinnitus patients have impaired capacity to perform certain cognitive tasks like tasks involving working memory and selective attention.

Chapter 3

Method

The current study was designed to investigate the effect of tinnitus on the temporal characteristics of the auditory system, speech perception ability in noise, and auditory working memory in persons with normal hearing sensitivity.

Research Design

A cross-sectional descriptive research was used to accomplish the aim of the current study.

Participants

Two groups of participant were included within the age range of 18-55 years (mean age: 38.1 years) To fulfill the objectives of the study. The clinical group included 20 participants (12 males and 8 females) with a complaint of tinnitus having normal hearing sensitivity. This group was divided into two subgroups; mild tinnitus (10 subjects; 6 males and 4 females) and moderate tinnitus (10 subjects; 6 males and 4 females). Tinnitus Handicap Inventory (THI) was administered in clinical group to assess the severity of tinnitus and according to which the group was divided into a mild (score of 18-36 on THI) and a moderate (score of 38-56 on THI) subgroup for comparison (Appendix-I). Control group included 20 age-matched participants with normal hearing sensitivity and without tinnitus. Mean age and age range of subjects participated in the study is given in the following table:

Table 1.

Mean age and age range of the participants

			No. of subjects	Age(years)	
				Mean	Range
Clinical Group	Mild	Males	6	35.3	22-51
		Females	4	39	23-55
		Total	**10**	**36.8**	**22-55**
	Moderate	Males	6	35	18-51
		Females	4	45.5	44-47
		Total	**10**	**39.4**	**18-51**
Control Group	Normals	Males	12	37.4	18-55
		Females	8	34	20-52
		Total	**20**	**36.1**	**18-55**

Participant Selection criteria

All the participants in the study were selected based on the following criteria;

Clinical Group

- All subjects had continuous tinnitus in one or both the ears for at least three months.
- All subjects had pure tone thresholds within 25 dB HL in octave frequencies from 250-8000 Hz for air conduction and 250-4000 Hz for bone conduction.
- Participants had an SIS score more than 80% in quiet.
- All the subjects had "A" type tympanogram.
- None of them had a history of ototoxicity and exposure to noise which might cause a hearing loss.
- None of them had an observable neurological symptom or any other general body weakness noticed or reported.
- None of them had an auditory processing deficit.
- None of them had any history of ear pain, ear discharge, and giddiness.
- None of them had any recent history of cold.

Control Group

- All subjects had pure tone thresholds within 25 dB HL in octave frequencies from 250-8000 Hz for air conduction and 250-4000 Hz for bone conduction.
- Participants had an SIS score more than 80%.
- All the subjects had "A" type tympanogram.
- None of them had a history of ototoxicity and exposure to noise which might cause a hearing loss.
- None of them had an observable neurological symptom or any other general body weakness noticed or reported.

- None of them had an auditory processing deficit.
- None of them had any history of ear pain, ear discharge, and giddiness.

Instrumentation

- A calibrated audiometer (Inventis Piano plus) coupled with an acoustically matched headphone (TDH-39) with MX-41/AR ear cushion and a bone conductor (Radio ear B-71) were utilized to estimate pure tone threshold, speech recognition thresholds and speech identification score in quiet and noise.
- Tympanometry and acoustic reflex thresholds (ART) were obtained using a calibrated immittance meter (GSI-TS).
- A Samsung NP-NCT 108 laptop with MATLAB software Version 7.9 (The MathWorks, Inc., 2009) was used to present the test material and record the response.
- A TDH-39 headphone with MX-41/AR ear cushion, calibrated for the output of computer at 80dB SPL was used to present the stimulus through the computer.

Testing Environment

All the basic tests were done in acoustically treated rooms with permissible noise level as per ANSI S 3.1 (1999) standards and the experimental evaluation was done in a quiet room.

Procedure

Written consent was collected from all the subjects for willingly participating in the study. All the subjects of both clinical and control groups were assessed for presence of hearing loss and middle ear pathology.

Case history

A detailed case history was obtained to find out whether the subject had any recent history of hearing loss or any middle ear pathology which may or may not cause a hearing loss. Case history also included the information about the tinnitus in the clinical group.

Otoscopy

Otoscopic examination was done to check structural integrity of sound conduction pathway and tympanic membrane.

Pure-tone audiometry

To ensure that the subjects had normal hearing, all the participants were subjected to pure tone audiometry with the octave frequencies from 250-8000 Hz for air conduction testing and from 250-4000 Hz for bone conduction testing.A modified version of Hughson and Westlake procedure (Carhart & Jerger, 1959) was used to obtain pure tone thresholds. The subjects who had behavioural thresholds within 25 dB in all the octave frequencies were considered for further testing.

Immittance Audiometry

Immittance audiometry was carried out to rule out the presence of any middle ear pathology. Tympanogram was obtained for a 226 Hz probe tone by sweeping the pressure in ear canal from +200 to -400 dapa and ipsilateral and contralateral reflexometry were conducted for 500, 1000, 2000 and 4000 Hz pure tone at the peak pressure. During this testing subjects were made to sit comfortably and asked not to swallow. A minimal admittance change of 0.03 ml after the onset of the reflex eliciting signal was considered as the presence of acoustic reflex.

Tinnitus pitch and loudness matching

All the subjects of the clinical group underwent tinnitus pitch and loudness matching.

Pitch Matching. The pitch matching for tinnitus was obtained by using methods of limits procedure. Puretone, narrow band noise and wideband noise were presented at 20 dB SL to the contralateral side to the ear in which the tinnitus was perceived in case of unilateral tinnitus. In cases with bilateral tinnitus, the signal was presented to the side contralateral to ear with predominant tinnitus or to the right ear if tinnitus was perceived equally loud in both the ears. The subject was instructed to indicate which of these signal types resembled most similarly to the pitch of the sound perceieved in their ear which was again varied continuously along the audiometric frequencies until the subject finds that the signal pitch and the pitch of their tinnitus are matched best. The signal frequency that matched best with the tinnitus pitch was considered as the pitch of the tinnitus and acted as a reference signal for the loudness matching of tinnitus.The range of the matched tinnitus pitch for mild tinnitus group varied from 500-8000 Hz for pure tone. The range of the matched tinnitus pitch in individuals with moderate tinnitus varied from 125 Hz-8000Hz for both puretone and broad-band noise.

Loudness Matching. The reference signal was presented to the contralateral side of the ear in which the tinnitus was perceived in cases of unilateral tinnitus. In cases with bilateral tinnitus, the reference signal was presented to the side contralateral to ear with predominant tinnitus or to the right ear if tinnitus was perceived equally loud in both the ears.The intensity of the signal was varied at a 5 dB step until the subject heard the sound which was the threshold for a particular signal. Then the intensity was further increased in 5 dB steps till the subject indicates that the signal is equally loud as tinnitus. The difference between the threshold and the level of the signal at which the loudness match was obtained is the loudness of the tinnitus.The mean intensity of the matched tinnitus loudness for mild tinnitus group was 21dB (range-6-45dB) whereas for moderate tinnitus it was 31 dB (range-15-40 dB).

The subjects who met the inclusion criteria mentioned above for different groups were included in corresponding groups in the study and further assessments were done; i. e. tests for temporal resolution, speech perception in noise and auditory working memory.

Tests of Temporal Resolution

Tests to assess temporal resolution involved GDT & MDT tests which was done by using Maximum Likelihood Procedure (mlp) toolbox. Mlp is implemented through Matlab (Grassi & Soranzo, 2009) by utilizing a large number of candidate psychometric functions. After every trial it estimates the probability (or likelihood) of achieving the listener response to all of the stimuli that have been presented by that trial and determines the subsequent stimulus, considering the psychometric function which gives the highest probability. Within about 12 trials, the mlp generally attains a reasonably stable estimate of the most likely psychometric function. This is then used to estimate the threshold (Green, 1990; 1993). The stimulus for mlp is generated using 44,100 Hz sampling rate. In the present study a three-interval, alternate forced-choice (3-AFC) method using mlp was used to track a 79.4% correct response criterion. For both GDT and MDT tests, all the subjects were given 5-6 practice items before the commencement of the test. The stimulus for all the tests was presented using TDH 39 head phones which was calibrated at 80 dB SPL.

Gap detection threshold. The gap detection threshold was assessed by obtaining the participant's ability to detect a temporal gap which was embeded in the center of a 500 ms broadband noise (Harris, Eckert, Ahlstrom, & Dubno, 2010). The noise was designed to have a 0.5 m cosine ramp at the beggining and the ending of the gap. This broadband noise was used for the GDT as its spectrum does not change with the insertion of the gap (Moore, 2003).

Modulation detection threshold. The modulation detection threshold was measured using a 500 ms Gaussian noise which was sinusoidally amplitude modulated at 8 Hz, 20 Hz, 60 Hz and 200 Hz modulation frequencies (Bacon & Viemeister, 1985). These modulation frequencies were selected as they cover the range of both high and low modulation frequencies. Low frequency modulations were used because speech is characterized by low modulations (Singh & Theunissen, 2003). Higher modulation frequencies were used to obtain a quantitative justification of the temporal resolution ability. Noise stimuli had two 10 ms raised cosine ramps at onset and offset. The subjects were asked to say which block had the modulated noise. Modulated and un-modulated noise were equated to total root mean square (rms) power. The modulation depth was varied according to the subjects response to track a 79.4% correct response criterion level. The modulation detection thresholds were expressed in dB by using the following relationship:

Modulation detection thresholds in dB = 20 log10 m.

Where m= modulation detection threshold in percentage.

Speech Perception in Noise

Speech perception in noise testing was done to measure understanding of 50 % of the words in sentences (SNR-50). The subjects were presented with sentence lists developed for the

Kannada Quick Speech in Noise test (Avinash, Methi, & Kumar, 2010). Each list contains 7 subtests mixed with 8-talker speech babble noise at different signal to noise ratio (SNR). The SNR in a list varied between +8 dB to -10 dB in 3 dB steps between each successive subtest. The SNR was made adverse when the subject repeats all the key words in a sentence. The signal and the noise were presented monaurally through a personal computer. The listener's task was to repeat the sentences presented and each correctly repeated keyword was awarded 1 point for a total possible score of 35 points per list. The SNR-50 was calculated using the Spearman-Karber equation (Finney, 1952) as:

SNR-50=i+1/2(d) -(d) (#correct)

Where;

i=the initial presentation level

d=the attenuation step size

w=number of keywords per decrement

#correct=total number of correct keywords

Tests of Auditory Working Memory

Auditory working memory was assessed using auditory digit span for the forward and backward phase. In this task cluster of digits were presented in random order with the increasing levels of difficulty. The numbers were recorded from one to nine and six lists were prepared with increasing level of difficulty with level 1 being the easiest and level 6 being the toughest. Level 1 had three digits while the level 6 contained eight digits, which were presented randomly. An inter stimulus gap of 250 ms was used for all the levels. The digits were recorded using the CSL software from a female speaker and was presented through the laptop. Participants were asked to repeat the numbers in the same order for forward digit span test and in reverse order for back digit span test. Auditory working memory capacity was calculated as the total number of digits that the person could successfully recall.

Statistical analysis

The data obtained was subjected to appropriate statistical analysis using SPSS software (version 20). Descriptive statistics was used to estimate the mean and standard deviation. To analyze the data across groups for various tests, independent t test, Multivariate analysis of variance, Kruskal-Wallis test and Mann-Whitney U test was done.

Chapter 4

Results & Discussion

The main aim of the study was to compare the effect of tinnitus on temporal resolution, speech perception in noise, and auditory working memory in individuals with normal hearing sensitivity. The data obtained was subjected to statistical analysis using SPSS software version 20. The following statistical analysis was carried out across the groups.

- Descriptive statistics was done to estimate the mean and the standard deviation for all the tests.
- The independent t test was done to see the significant difference between the mild and moderate tinnitus category for all the tests.
- Multivariate analysis of variance (MANOVA) was done to compare the performance between groups for MDT, SPIN and auditory working memory.
- Kruskal-Wallis test was done to compare GDT between the control group vs. mild and moderate tinnitus groups..
- The Mann-Whitney U test was done for GDT to compare which two groups differed significantly.

The results of the study are discussed under the following headings.

- Effect of tinnitus on temporal resolution
- Effect of tinnitus on speech perception in noise
- Effect of tinnitus on auditory working memory

Effect of tinnitus on temporal resolution

The temporal resolution of different groups was assessed through gap detection test and modulation detection test.

Gap Detection Test

Figure-1 shows the mean GDT scores for all the groups along with one standard deviation (SD) bar. In the figure, x-axis represents the various groups and the y-axis represents the gap detection threshold (ms). It can be noted that GDT scores are poorer for individuals with tinnitus compared to those without tinnitus.

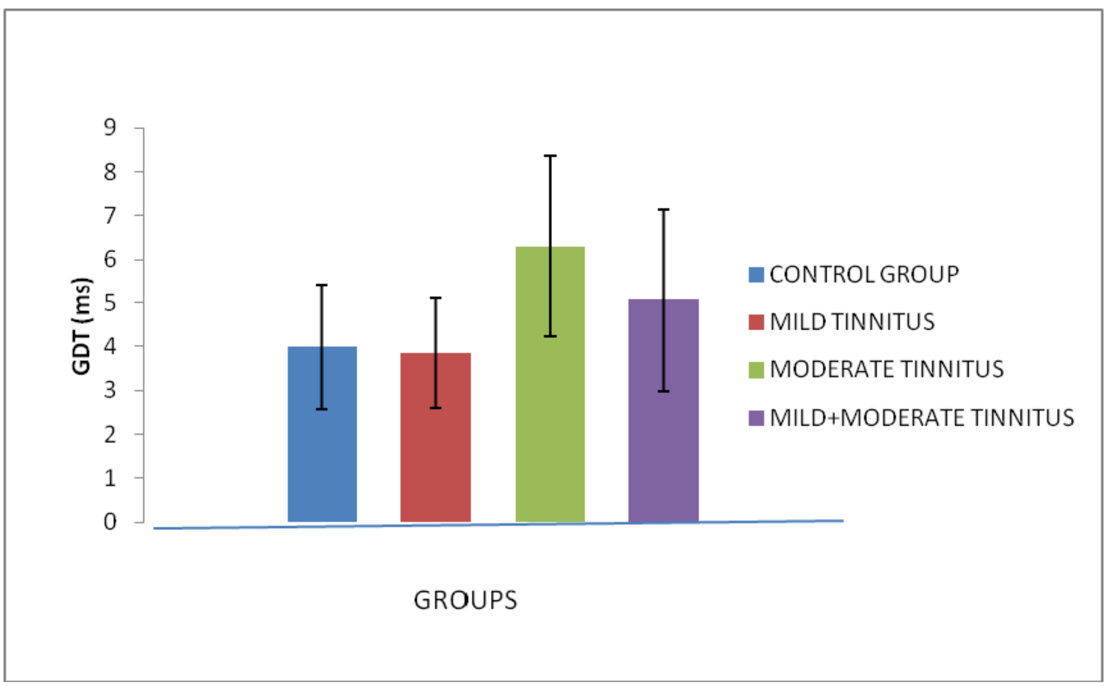

Figure-1: Mean scores and one-standard-deviation error bars of GDT for control & tinnitus groups.

The independent t test was done to see the significant difference in GDT between mild and moderate tinnitus groups. The results showed that there was a significant difference in GDT between both the groups ($t= -3.212$; $p< 0.05$). As mild and moderate group showed a significant difference, further to assess significant differences across control and clinical groups, Kruskal-Wallis test was performed. Results revealed that there was a significant main effect of groups on GDT [$\chi(2) = 11.543$; $p<0.05$). Mann-Whitney U test was done later to determine which two groups significantly differed. The comparison showed that GDT for individuals with moderate tinnitus was significantly poorer than those for individuals with mild tinnitus ($Z=-2.615$;$p<0.05$) & the control group ($Z=-3.260$;$p<0.05$). Whereas the difference in GDT scores between control group & mild tinnitus groups was statistically insignificant ($Z=-0.287$;$p>0.05$).

Modulation Detection Test

The MDT test was carried out for four different modulation frequencies (8, 20, 60, 200 Hz). Figure-2 represents the mean and SD of MDT at all the modulation frequencies for both control and clinical groups. In the figure x-axis represents the various groups at different modulation frequencies and the y-axis represents the modulation depth (dB). The figure shows that individuals without tinnitus had better MDT compared to those with tinnitus. Moreover, individuals with moderate tinnitus had poorest MDT values followed by those with mild tinnitus, with the best thresholds obtained by those individuals without tinnitus.

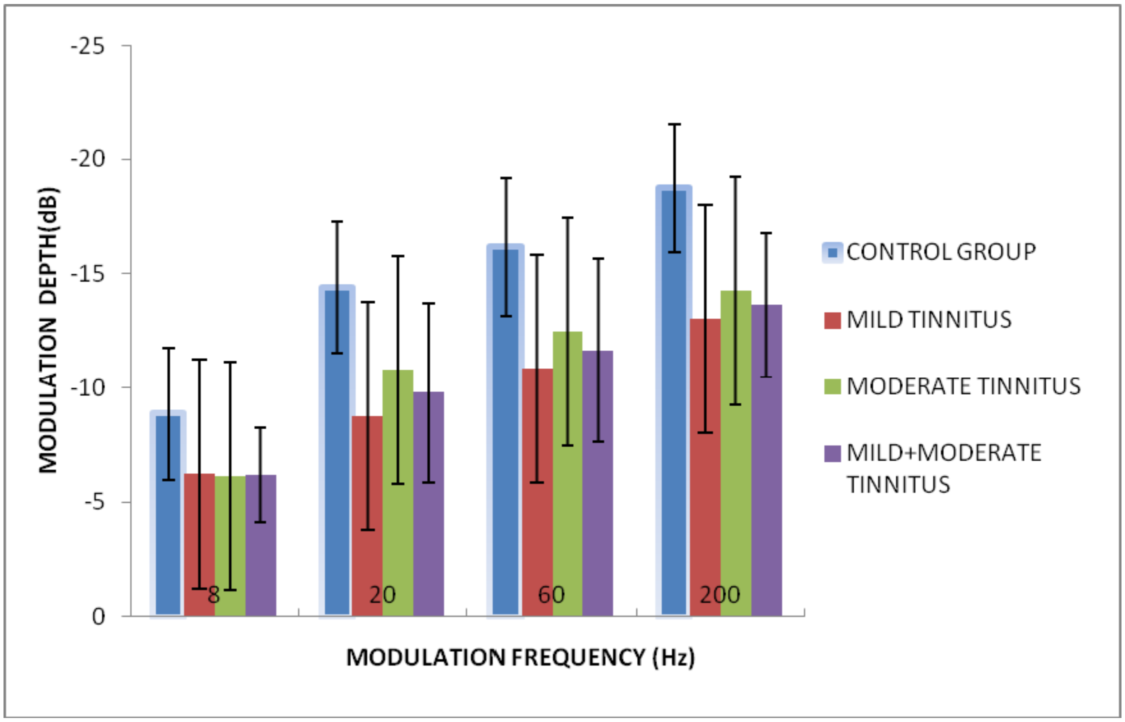

Figure-2: Mean scores and one-standard-deviation error bars of MDT at 8, 20, 60, 200 Hz for control and tinnitus groups.

The independent t test was done between the mild and moderate tinnitus groups to compare the MDT and results showed that MDT obtained from both the groups were statistically insignificant. Since the independent t test did not show any significant difference between the mild and moderate tinnitus groups, data obtained from the mild and moderate groups were combined for further analysis. Multivariate analysis of variance (MANOVA) was done to estimate the significant difference in mean thresholds of MDT across groups for the different modulation frequencies. The results of the analysis show that there was a significant difference between both the groups which is given in Table 2.

Table 2.

F-value and significance level of MDT at various frequencies between control and clinical groups.

MDT frequency	**8 Hz**	**20 Hz**	**60 Hz**	**200 Hz**
F (1,38)	20.941	15.439	10.419	10.356
Significance level	p<0.05	p<0.05	p<0.05	p<0.05

The findings of the current study showed that individuals with moderate tinnitus need larger silent intervals to detect a gap within the noise than individuals with mild tinnitus & than those without any complaint of tinnitus. These findings of the present study are in consistent with the previous studies done by Sanches et al. (2010), Gilani et al. (2013) & Haas et al. (2012). However, in these studies different degree of tinnitus to compare the temporal resolution were not assessed as in the present study.

In a study by Fournier and Hebert (2012) they assessed gap detection in individuals with tinnitus and they reported that the tinnitus group displayed a deficit in gap processing for both low and high background noise frequencies. The reason for poor gap detection could be that ongoing tinnitus mask the gap and results in impaired gap detection. Sanches et al. (2010) used GIN test in normal hearing listernes to evaluate the auditory temporal resolution ability on 18 individuals with tinnitus and 23 individuals without tinnitus. They reported that control group detected shorter gaps than the clinical group. Haas et al. (2012) also pointed out longer GDT in tinnitus subjects compared to non-tinnitus subjects and hypothesized that this could be because of some changes in neural activity in tinnitus patients which might prolong.

In the current study, individuals with tinnitus needed greater modulation depth in compared to individuals without tinnitus to detect a modulation in the noise in a wide range of modulation frequencies which suggests a poor temporal resolution ability in the affected population. However, a temporal processing ability to detect a modulation was reported to be similar across the different degrees of tinnitus. To the best of our knowledge, the effect of tinnitus on MDT has not been studied earlier, hence there are no supporting studies for the same.

Thus, the results of both GDT and MDT showed an impaired temporal perception in clinical group compared to control group which is in accordance to the literature data. The reason for the same could be due to the defects in neural structures in the central auditory nervous system which has resulted in the perception of tinnitus and could also impair temporal perception. However, mild tinnitus group did not show a deficit in GDT, but their MDT was poor. Thus it can be concluded that MDT is a more sensitive tool to assess the effect of tinnitus on temporal resolution.

Effect of tinnitus on speech perception in noise

The SNR-50 was calculated to assess the speech perception performance in the presence of noise. The SNR-50 was calculated using the Spearman-Karber equation (Finney, 1952) as:

SNR-50=i+1/2(d) -(d) (#correct)

Where;

i=the initial presentation level

d=the attenuation step size

w=number of keywords per decrement

#correct=total number of correct keywords

Figure-3 depicts the mean and SD of SNR-50 values for all the groups. In the figure x-axis represents the various groups and the y-axis represents SNR-50 (dB). It is evident from the figure that people with tinnitus had poorer SNR-50 values compared to those without tinnitus.

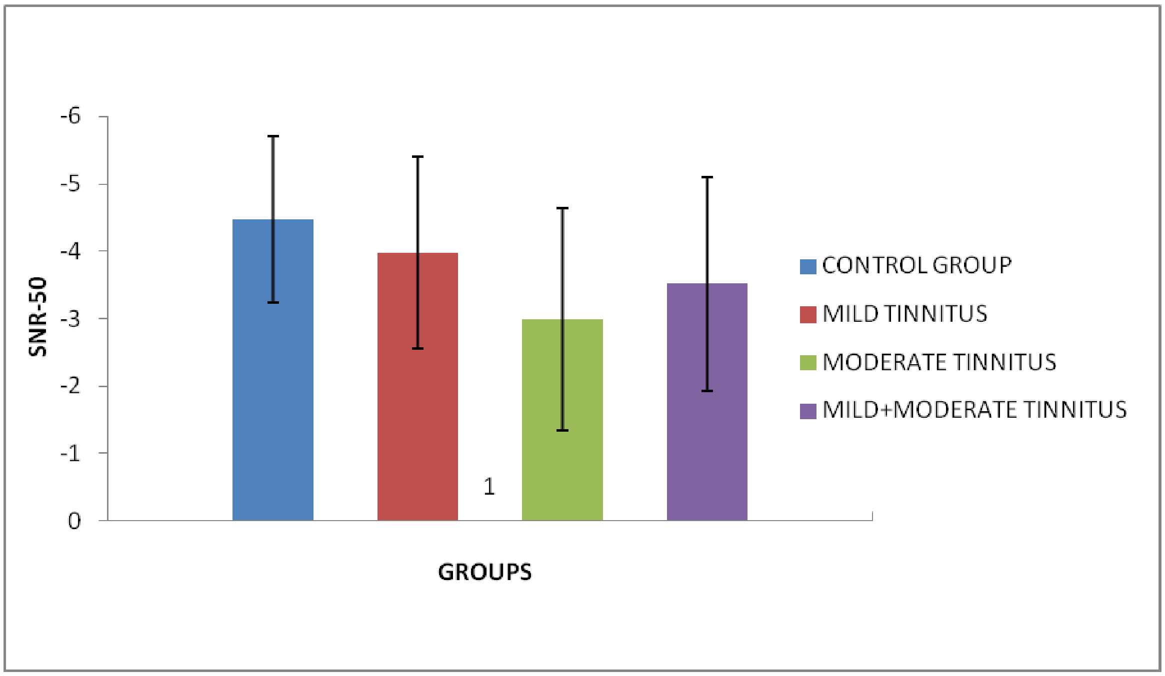

Figure-3: Mean scores and one-standard-deviation error bars of SNR-50 values for control & tinnitus groups

The independent t test was done between the mild and moderate tinnitus groups to compare the SNR-50 and results revealed that there was no significant difference in SNR-50 values between the tinnitus groups. Since the independent t test did not show any significant difference between the mild and moderate tinnitus groups, data obtained from the mild and moderate groups were combined for the further analysis. MANOVA was done to estimate the significant difference in mean SNR-50 thresholds and it showed a statistically significant main effect across groups [$F(1,38) = 4.805$; $p < 0.05$] in SNR-50.

The results of the current study suggest that the ability to perceive speech in noise is affected in individuals with tinnitus compared to those without tinnitus. Similar findings have been reported in the past by various authors (Newman et al., 1994; Huang et al., 2007; Ryu, Ahn, Lim, Joo & Chung 2012; Hennig,Costa,Urnau,Becker & Schuster, 2011; Soalheiro et al., 2012**)**. Again the speech perception ability in noise was asymptote across the severity of tinnitus.

Hennig,Costa,Urnau,Becker and Schuster,(2011) evaluated speech recognition in the presence of competitive noise in normal hearing individuals with tinnitus and hyperacusis. They concluded that both the groups performed similarly for speech recognition in silence, but a lower level performance on speech perception in noise was seen in tinnitus patients when compared with normal-hearing individuals without complaints of tinnitus and hyperacusis.

The reason of poorer speech understanding ability in the presence of noise could be attributed to the fact that tinnitus interferes with the speech perception. Also the role of the medial olivary cochlear system in the recognition of auditory stimuli in the presence of competitive noise (Breuel, Sanchez, Bento, 2001; Grataloup, Hoen, Veuillet, Collet, Pellegrino, 2009) is well known and a disorder in this system is connected to the mechanism of tinnitus (Breuel, Sanchez, Bento, 2001). Thus, the normal hearing individuals who have complaints of tinnitus may have a problem in such communication situations due to a change in the functioning of the efferent fibers of the medial olivary cochlear system.

Effect of tinnitus on auditory working memory

The auditory working memory was assessed through forward digit span (FDS) & backward digit span (BDS). Figure-4 & 5 represents the mean and SD of FDS & BDS scores respectively, for both control and clinical groups. In the figure x-axis represents the various groups and the y-axis represents FDS/BDS span. The figure shows that mean FDS and BDS was poorer in individuals with tinnitus than those without tinnitus.

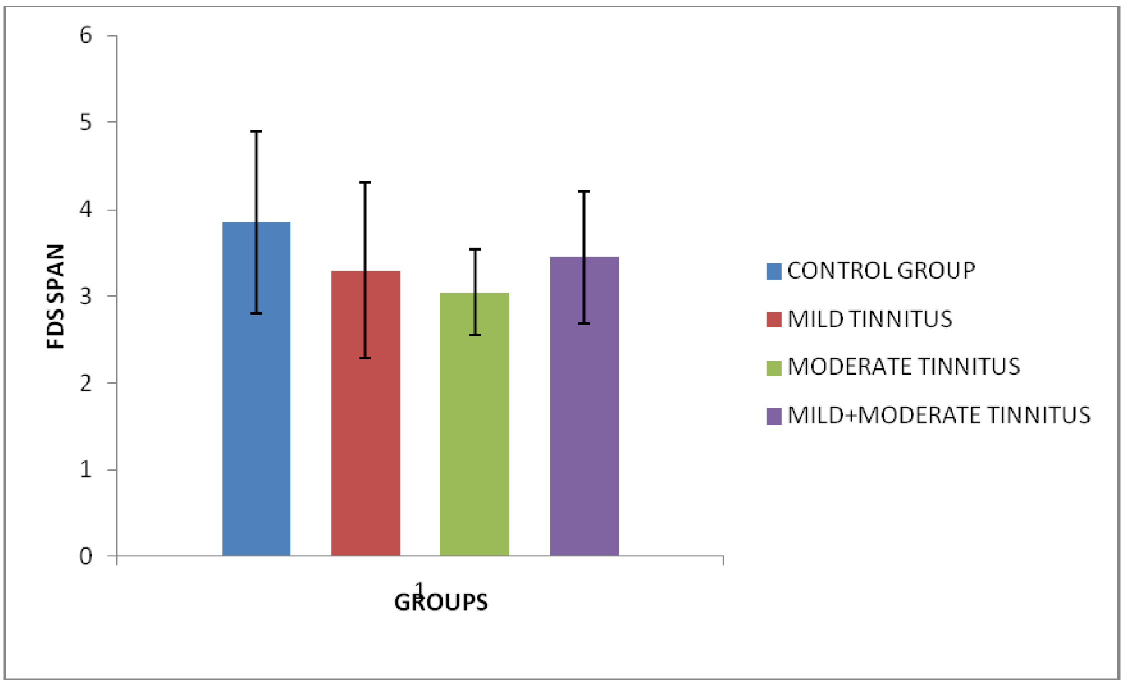

Figure-4: Mean scores and one-standard-deviation error bars of FDS score for control & tinnitus groups.

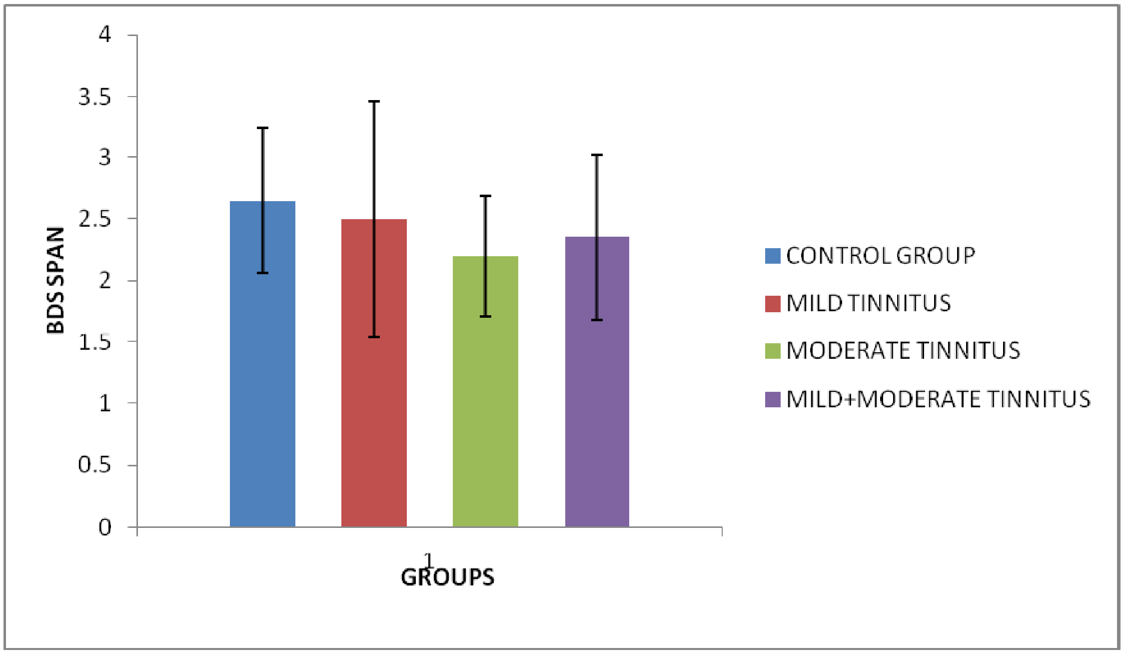

Figure-5: Mean scores and one-standard-deviation error bars of BDS score for control & tinnitus group

The independent t test was done again between the mild and moderate tinnitus groups to compare the FDS and BDS. The results revealed that there was no significant difference in FDS and BDS span across the tinnitus groups ($p>0.05$). Thus, as the independent t test did not show any significant difference between the mild and moderate tinnitus groups, FDS and BDS data obtained from the mild and moderate groups were combined for the further analysis. Again MANOVA was done to estimate the significant difference in mean FDS and BDS between control and clinical groups and results showed that the difference was statistically insignificant between groups for both FDS and BDS. The results are shown in Table 3.

Table 3.

F-value and significance level of FDS and BDS between control and clinical groups.

MDT frequency	**FDS**	**BDS**
F(1,38)	0.07	0.165
Significance level	p>0.05	p>0.05

There was no significant main effect of tinnitus on either of the auditory working memory tasks (FDS & BDS) which suggests that the auditory working memory remains unaffected by the impact of tinnitus. Studies in the literature also support the present findings. Acrani and Pereira (2010) studied the effect of tinnitus on selective attention using dichotic digit test and they reported that there was no difference between the individuals with and without tinnitus.

However, the study done by Susan, Catherine and Gary (2006) suggests that tinnitus affects auditory verbal working-memory and visual divided-attention and in-turn cognition. In their study, they concluded that the tasks which require lower demand, involving the automatic task of recognizing words and reveal a significant difference. Similarly, Andersson, et al., (2000) investigated cognitive interference due to tinnitus using a modified version of the Stroop color-word test. They concluded that tinnitus patients have impaired cognitive performance overall, but the result could have been affected by hearing impairment.

In the present study, the findings in auditory working memory task between the control group and the clinical group could be contributed to the fact that the task used in the present study (FDS & BDS) was not sensitive enough to tap the deficits in the auditory working memory. Moreover the participants in the previous studies involved individuals with tinnitus along with hearing impairment. Thus, what led to the decline in the cognitive ability could not be concluded.

Thus, the null hypothesis is rejected for the first three objective. However, the relationship between auditory working memory and GDT, MDT, SPIN scores was not assessed in the present study as mentioned in the objectives. This is due to the fact that auditory working memory itself did not show any significant difference between both the groups.

Chapter 5

Summary and Conclusion

Tinnitus is defined as the conscious experience of sound that originates in the head and it is often associated with a lot of auditory deficits like hearing loss, hyperacusis. Earlier studies have also been conducted to explore the pathophysiology of tinnitus and the treatment directions which can be related to the auditory system. Several studies show that tinnitus affects temporal perception, speech perception in noise and cognition. However, all this has not been studied in a single individual with tinnitus having normal hearing sensitivity.

The present study aimed to investigate the effect of tinnitus on the temporal resolution, speech perception in noise, and auditory working memory in individuals with normal hearing sensitivity. The study was conducted on 20 individuals with tinnitus with 10 subjects each in mild and moderate tinnitus category. The results were compared with 20 age matched individuals without tinnitus. Psychoacoustic measures of tinnitus such as pitch matching and loudness matching was done on clinical group. Tinnitus Handicap Inventory was also administered to clinical group to categorize them under mild and moderate groups. All the participants in this study were subjected to the following tests.

- Gap detection test and modulation detection test at 8, 20, 60, 200 Hz to assess the temporal resolution of the auditory system;
- Kannada Quick-SIN test to assess speech perception in noise and
- Forward and backward digit span test to assess auditory working memory

The data obtained from the study was subjected to statistical analysis using spss software version 20. Data was analyzed using independent t test, MANOVA, Kruskal-Wallis test and Mann-Whitney U test. The findings of the study were as follows:

- Individuals with tinnitus had higher gap detection thresholds compared to those without tinnitus & individuals with moderate tinnitus had higher GDT compared to those with mild tinnitus and control group.

- Individuals with tinnitus had a poorer modulation detection threshold when compared to those without tinnitus. But, within the clinical group itself (mild & moderate tinnitus) MDT values did not differ significantly.

- Individuals with tinnitus had higher SNR-50 values in comparison to those without tinnitus. But, SNR-50 values did not differ across different degrees of tinnitus (mild & moderate).

- Auditory working memory assessed through FDS & BDS did not differ significantly between both the control and clinical group.

From the findings of the current study, it is concluded that tinnitus has an effect on aspects of auditory perception like temporal resolution, speech perception in noise in individuals with normal hearing. This could be due to subtle changes in the central auditory system which is not shown in the pure tone audiogram. This findings are supported in the literature.

However, the relationship between auditory working memory vs. temporal perception and speech perception in noise could not be established. This is because auditory working memory did not differ across groups. Thus, whether these deficits are due to poor auditory working memory could not be concluded. Thus, the use of a varied number of tests to assess auditory working memory and larger sample size is warranted in future research.

Chapter 6

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