# COMPARISON BETWEEN AUDITORY WORKING MEMORY, TEMPORAL RESOLUTION AND AUDITORY CLOSURE ABILITIES IN INDIVIDUALS WITH TYPE 2 DIABETES MELLITUS

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# CERTIFICATE

This is to certify that this dissertation entitled **'Comparison between Auditory Working Memory, Temporal Resolution and Auditory Closure Abilities in Individuals with Type 2 Diabetes Mellitus'** is the bonafide work submitted in part fulfilment for the degree of Master of Science (Audiology) of the student Registration Number: 18AUD040. This has been carried out under the guidance of the faculty of the institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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# CERTIFICATE

This is to certify that this masters dissertation entitled **'Comparison between Auditory Working Memory, Temporal Resolution and Auditory Closure Abilities in Individuals with Type 2 Diabetes Mellitus'** has been prepared under my supervision and guidance. It is also being certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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# DECLARATION

This is to certify that this dissertation entitled **'Comparison between Auditory Working Memory, Temporal Resolution and Auditory Closure Abilities in Individuals with Type 2 Diabetes Mellitus'** is the result of my own study under the guidance of Dr. Prawin Kumar, Associate Professor 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.

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# ABSTRACT

*The main aim of the study was to find the relationship among auditory working memory, temporal resolution abilities and speech perception in noise (SPIN) in individuals with type 2 diabetes mellitus (T2DM). To measure and compare performance of auditory working memory, temporal resolution, speech-in-noise test was done for individuals with and without type 2 diabetes mellitus. Thirty participants, out of which 14 individuals without T2DM and 16 individuals with T2DM in the age range of 50-60 years were considered for the study. The T2DM diagnosis was confirmed by general physician and had diabetes from at least last 5 years. All the participants had hearing sensitivity within normal limits based on basic audiological test battery. Auditory working memory tests include forward digit span, backward digit span, ascending sequence test and descending sequence test administered for both groups. Temporal resolution ability was assessed using gap detection test and auditory closure deficit was assessed using SPIN at 0 dB SNR and -5 dB SNR for both groups. Results revealed poorer mean scores of auditory working memory tests, GDT & SPIN for clinical group in comparison to control group. However, no significant differences were observed between control and clinical group for working memory and SPIN test, whereas GDT showed statistical significant difference between groups. Correlation analysis revealed no association between working memory, temporal resolution and auditory closure abilities. It probably indicates these three domains are independent to each other and assess different areas of the auditory system.*

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# CHAPTER 1

# INTRODUCTION

Type 2 diabetes mellitus (T2DM) is a chronic metabolic disorder characterized by hyperglycemia due to insulin resistance in our body. The prevalence of T2DM is rising globally and the same effect is seen in India also since the last few years. T2DM is most common form of diabetes and reported to be present in about 2.4% of the rural residents and 11.6% of the urban residents (Ramachandran, 2002). The exact root cause of T2DM is unknown although genetics and environmental factors, such as individual overweight and inactive lifestyles are the some of the causative factors. T2DM is associated with several documented adverse health effects in older individuals such as visual, cardiovascular and renal dysfunction (Centres for Disease Control and Prevention, 2014).

As reported in literature, the damage to the auditory system due to T2DM are commonly reflected as high-frequency sensorineural hearing loss, possibly due to the cochlear and 8th nerve damage (Makashima & Tanaka, 1971; Taylor & Irwin, 1978; Dejong, 1982; Triana et al, 1991). There are studies reported effects of T2DM on cognitive abilities (Nilson et al. 2007; Cox et al., 2002). Similarly these individuals exhibit more time to perform the tasks such as verbal recall and complex information processing due to poor cognitive abilities. One of the histopathological study reported degeneration of the gray matter in T2DM patients (Bryan et al., 2014) along with micro-structural changes in the white matter. In addition, they recommended that those changes in the structure could be attributed to cognitive impairments caused by (Zhang et al., 2014).

The psychophysical method of threshold sensitivity and temporal processing in hearing were assessed. Study done by Humes and colleagues in year 2012 assessed higher-level of auditory processing in the older adults using different paradigms such as temporal masking, gap-detection thresholds, and temporal-order identification measures on individuals with diabetes. There are studies reported poorer temporal resolution abilities among T2DM patients (McCrimmon, Deary, & Frier, 1997; Mishra, Sanju, & Kumar, 2016; Pirasteh et al., 2018).

Speech perception in noise is one of the most evident difficulties reported by T2DM patients. Study done by Bajaj and colleagues reported that speech perception abilities among individuals having diabetes more than five years showed a poor speech-in-noise scores and indicate auditory closure deficit in these individuals (Bajaj et al., 2014). Most of the studies reported based on the evidence from temporal resolution and speech perception in noise are limited to the young adult population. Based on the above background, present study is designed to explore the cognition abilities, temporal resolution abilities, and speech perception abilities in presence of adverse listening conditions among T2DM patients to understand the functional difficulty reported if any in initial stages of the diabetes with intact peripheral hearing acuity.

## 1.1 Need for the Study

Research reported in the literature revealed involvement of cognition, temporal processing and auditory closure abilities in individuals with T2DM (Makashima & Tanaka,1971; Taylor & Irwin, 1978; Dejong, 1982; Triana et al, 1991; Andreadou et al., 2012; Bajaj et al., 2014; Mishra et al., 2016 ; Mythri, Girish, & Manjunath, 2017). It is well known fact that the metabolic disease like T2DM is having deleterious effect on the whole body including auditory system and cognition over the years. However, there are studies reported change in the micro-structure of the cochlea, and auditory nerve conduction due to ageing rather than T2DM (Dubno et al., 1984; Stuart & Phillips, 1996; Moore, 1996). Although study reported glycaemic level affecting the auditory function in diabetes patients and the duration of diabetes showed no correlation with the hearing function (Marinkov et al., 2016). Few studies attempt to find out the effect of tinnitus on speech perception in noise, auditory working memory and temporal resolution in normal hearing individuals (Sahoo & Jain, 2014). Whereas some of the studies reported reduction in working memory, poor temporal resolution abilities and reduced perception abilities in presence of noise due to type 2 diabetes mellitus rather than aging (Frisina, Mapes, Kim, Frisina, & Frisina, 2006; Mishra et al., 2016; Prabhu & Shanthala, 2016; Bedi & Dang, 2017). While the elderly diabetes patients showed no association with the cognitive test performance but might increases the risk of vascular dementia (Hassing, Johansson, Pedersen & Nilsson, 2003). Hence, there is a need to validate the relationship among working memory, temporal resolution abilities and speech perception in noise in individuals with T2DM. Therefore, present study is considered to explore the correlation between working memory, temporal resolution abilities and speech perception in noise in individuals with T2DM.

## 1.2 Aim of the study

The aim of the present study was to establish the correlation among working memory, temporal resolution abilities and speech perception in noise (SPIN) in Individuals with T2DM.

## 1.3 Objectives of the study

The following were the objectives of the study:

1. To assess the auditory working memory (forward digit span, backward digit span, Ascending sequence and descending sequence) in individuals with T2DM and compared with healthy individuals.
2. To assess the temporal resolution abilities in individuals with T2DM and compared with healthy individuals.
3. To evaluate the speech perception in noise in individuals with T2DM and compared with healthy individuals.
4. To assess if there is any correlation among auditory working memory, temporal resolution abilities and speech perception in noise in individuals with T2DM.

# CHAPTER 2

# REVIEW OF LITERATURE

The Auditory system consists of peripheral and central structure which is vulnerable to the continuous increase in the sugar level in the human beings. In addition, the lower brainstem and higher order system do have a harmful effect in the auditory structure through physiologic, metabolic changes or the degeneration which leads to the problem in processing of the acoustic signal. The higher order processing deficit due to T2DM could be an auditory closure deficit, temporal resolution deficit and also affect working memory. There is several literature which points towards the auditory processing deficit in diabetic patient (Frisina et al.,2006; Humes et al., 2013; Bajaj et al., 2014; Konrad et al., 2015; Akinpelu et al., 2014). The review of literature is discussed below with reference to effect of T2DM on hearing acuity, cognition, working memory, temporal resolution and auditory closure deficit.

## 1.1. Effect of T2DM on hearing acuity

As reported in literature, the damage to the auditory system due to T2DM is commonly reflected as high-frequency sensorineural hearing loss (SNHL) could be due to the inner ear and auditory nerve damage (Makashima & Tanaka, 1971; Taylor & Irwin, 1978; Dejong, 1982; Triana et al., 1991). One of the case study done by Makashima and tanaka (1971) they studied histopathological and audiological evaluation on 4 older adults with diabetes mellitus , They observed significant degeneration in the neuronal & vascular lesions(Auditory nerve , superior olivary nuclei, inferior colliculus and medial geniculate body). In the auditory centers of both temporal lobes, ganglion changes in diabetes and also they reported bilateral symmetrical sensorineural hearing loss at 8 kHz, they suggested hearing loss in diabetes is mainly due to degeneration in those structures. Another histopathological study done by Triana et al, (1991) they conducted study on rats, they observed the effect of diabetic state on the cochlear structures. They observed significant damage of OHC due to NIDDM, the author reasoned the outcome due to two factors such as genetic predisposed for glucose intolerance and hyperglycemia. Dejong (1982) explained about the alteration in the central nervous system in case of diabetes mellitus, they explained two processes such as myelopathy they observed degeneration of the nerve tracts and encephalopathy involves de generation of ganglion cells and nerve fibers in the cerebrum, brain stem, and cerebellum. Further review article done by Taylor et al., (1978) reported diabetes patients showed more risk for hearing loss .The prevalence of SNHL among 172 participants was 67.44% in the diabetic patients while 23.26% in the non-diabetic control group. Further, the degree of hearing loss observed among 58 diabetic patients who had hearing loss, predominantly found mild degree (56.9%) and followed by moderate degree (39.7%). Among these individuals, hearing thresholds in the high frequency range of 3 kHz to 8 kHz were more significantly affected (Jyothi & Malli, 2019). In another study, Vignesh (2014) and colleagues reported raised high frequency thresholds at all frequencies in the high frequency audiometry in young adults with T2DM group than control group. But they also reported no threshold difference at 16 kHz frequency, suggesting an indicator of the early onset of the hearing loss and monitoring progression among diabetes patients than conventional audiometry (Vignesh, Jaya, Moses & Muraleedharan, 2014). In contrast, Sameli et al (2017) reported significantly worse hearing thresholds and speech recognition abilities among 910 participants in the age range of 35-74 years in diabetic patient in comparison to non-diabetic. However, after adjusting for age, gender, and the occurrence of hypertension, no major differences were found among the groups. The reason reported in the study could be due to young age, duration and adequate glycemic control. Another study showed similar results in the pure tone audiometry findings among 100 diabetes patients with matched control subjects. But at the older age group (>50 years) and with the increase in the period of diabetes the hearing were reported to be worse (Joshi, Galagali & Singh, 2017).

Li et al (2018) Studied hearing function in the participants with the age range (20-70 years). They suggested high frequency sensorineural hearing loss was more reported in Type 2 diabetic patients than pre-diabetes and also significant increase in high frequency threshold where the DPOAE amplitude was not significant except amplitude at 6 kHz. Further, these results imply damage of hearing function due to high blood sugar. Although another study done on 152 type diabetes patients (age range -30-60 years). They evaluated PTA, TEOAE, and DPOAE tests among all the participants, they obtained showed alteration in otoacoustic emissions analysis was obtained approximately 50% flat sensory-neural hearing loss along with absent of TEOAE & DPOAE. The result suggest that association of early outer hair cell dysfunction and thus can predict cases might have damage at neural level or central auditory processing deficits hence recommended to validate with proper assessment of central auditory system in T2DM patients (Ferreira et al., 2016).

Several studies reported in literature about the utility of ABR in diabetic patients to assess the functioning of auditory nerve (Durmus, Yetiser, & Durmus, 2004; Morales

2005; Forogh, Zeinolabedini, Akbari, & Mianehsaz, 2013; Akinpelu, Mujica-Mota & Daniel, 2014). Study done by Durmus et al., (2004) studied Auditory brainstem responses in 43 patients in the age range of 1-33 years, they were divided into two groups NIDDM (n=26) & IDDM (17) with normal hearing sensitivity. The results showed all three primary peaks (I, III & V) of ABR latencies prolonged in diabetes patients. Further, the interpeak latencies of peak III and V were reported to be statistically significant in both the groups. They reported long term consequence of diabetes leads to slow nerve conduction velocity in these patients. In addition, the considerable delay in the peak V latency and inter-peak latencies I-V and III-V intervals probably indicates the diabetic neuropathy which is especially noticeable at the upper brainstem level (Durmus, Yetiser & Durmus, 2004; Morales, 2005). Similarly another study had done by Forogh (2013) assessed PTA and ABR among 60 participants in the age range of 30-45 years. They reported increase in pure tone thresholds at 2, 4 & 8 kHz in diabetic patient but within the normal range. However, ABR latencies were affected in half of the participants in spite of hearing threshold being normal and good glycemic control. In addition, prolonged I-III, III-V, I-V inter wave latencies indicate the involvement of the retrocochlear and brain stem involvement (Forogh, Zeinolabedini, Akbari, & Mianehsaz, 2013). One of the review article published by Akinpelu, Mujica-Mota and Daniel (2014) reported a greater mean pure tone threshold & prolonged Wave V latencies of auditory brainstem response among diabetic patient in comparison to the non-diabetic patient. While the cortical potential were the response altered among the diabetic patients suggesting the impact of attention, memory, age factor and hearing deficit. Whereas Konrad et al (2016) evaluated cortical potential in 114 control and 108 diabetes participants in the age range of 50-70 years. They reported N1 latency changes with respect to age and diabetes and P2 latency changes only with T2DM not age effect .Thus observation implies higher order processing deficit though no report of peripheral problem. Another research done by Kumar and Bhat (2018) confirmed the findings of prolonged latencies and reduced amplitude of P1, N1 and P2 wave among participants with T2DM compared to control group in the age range of 40-60 years, they found positive correlation for ALLR latency and duration of T2DM. While negative correlation was obtained for amplitude of ALLR. They reported difficulty in encoding of speech sounds at the cortical level even though hearing was normal in individuals with T2DM (Kumar , Bhat & Varghese, 2018).

### 1.2. Effect of T2DM on cognition

There are literature reported an impact on higher level auditory processing and involvement of cognitive system i.e. delayed information-processing speed in individuals with T2DM. The above finding is based on the evidence of histopathological alterations in global network properties and white matter topological network i.e. uncinate fasciculus, superior and inferior longitudinal fasciculus in both hemisphere and also in the corpus callosum (Reijmer et al., 2013). They also reported even though cognitive decline was seen which could not significantly disrupt the quality of life among individuals with T2DM at the preliminary stage (Reijmer et al., 2010). The impact of diabetes on cognitive function showed prolonged latency in addition of hypertension and longer duration of the diabetes showed further prolonged latencies of P300 potential (Andreadou, Mitrakou, Constantinides & Triantafyllou, 2012; Sindhuja & Ramya 2020). Winkler and colleagues studied the association of T2DM with Mild Cognitive

Impairment with cognitive tests such as Verbal memory, immediate recall, delayed recall, speed of processing , executive functions, verbal fluency and visual spatial organization in different subtype like middle aged (50-65 years) and old age group (66-80 years old) and also with gender group. The authors noted MCI with T2DM in middle-aged group and also in the subtype analysis women group showed stronger association in amnestic MCI where men group with non-amnestic MCI. But no such relation was obtained in elderly individuals (Winkler et al., 2014). Some of the review articles reported that individuals with T2DM had more risk for Alzheimer's disease (Cheng, Huang, Deng and Wang, 2012; Felice, 2013). Another study which supported the above statement where the Mini-Mental State Examination test was conducted on 346 type 2 diabetic patients, the score obtained was 26 points (16 - 30) although those participants who required medications got more poorer score (12.1%) had potential diagnosis of dementia and they suggested with increase in the duration of disease could associate cognitive decline (Alencar, Cobas & Gomes 2010).

Study done by Sommerfield and colleagues reported that individuals with T2DM are not only having reduced (poor) auditory processing system but also information processing and working memory are affected. The cognitive tasks were administered on 20 subjects with T2DM (median age = 61.5), they reported several to be affected in individuals with T2DM such as the elevator counting with reversal, digit span backwards, four-choice reaction time test and letter/number sequencing. Whereas simple test of information processing task, memory, and attention are not relatively affected due to acute hyperglycemia (Sommerfield, Deary & Frier, 2013). On the other hand, evidence suggested that in chronic hyperglycemia there is an existence of peripheral neuropathy or retinopathy, which might lead to the cognitive impairment associated with diabetes (Dorsemans, Couret, Hoarau, Meilhac, Hellencourt & Diotel, 2017). Individuals with T2DM exhibit more time in tasks such as verbal recall and complex information processing due to poor cognitive abilities (Nilson et al., 2007; Cox et al., 2002). One of the histopathological study reported degeneration of the gray matter in individuals with T2DM (Bryan et al., 2014) along with micro-structural white matter modifications (Zhang et al., 2014). In addition, reported cognitive impairment incurred by T2DM might be related to alterations in this structural system (Zhang et al., 2014). Another electrophysiology evidence Hazari et al., 2011 studied P300 potentials on diabetes patients .in the age range of 40-65 years .They reported that prolonged P300 latencies when the duration of diabetes greater than 5 years and also the cognitive decline was further increased with the association of T2DM and hypertension (Hazari, Reddy, Uzma, & Kumar, 2011).

### 1.3. Effect of T2 DM on working memory

Chang and colleagues reported individuals with T2DM associated with an almost 2-fold elevated risk of dementia (Cheng, Huang, Deng & Wang, 2012). Study done by Mythri and colleagues were evaluated working memory performance on 200 participants in age range of 40-65 years. They found reduced performance on auditory verbal learning test, working digit span test, visual reproduction test, verbal fluency test, and validation span test among diabetes group in comparison to healthy individuals. They further concluded that the factors such as duration, blood sugar levels, gender, age, and glycemic control would result in the decline in memory status in diabetic patients (Mythri, Girish, & Manjunath, 2017). Similar observation was done on 114 diabetics and 119 normal subjects in the age range of (40-60 yrs.). They conducted short term memory test such as Auditory verbal learning test, Visual reproduction test & Verbal fluency test. They administered working memory tests such as working digit span test and validation span test. The result revealed significant decrease in working memory and short term memory in diabetic patients and also seen in both male and female group. Further, elderly diabetics aged (> 55yrs) showed greater cognitive decline compared to younger age group. They also speculate possible cause such as hyperglycemia, hypoglycemia, vascular dementia and insulin resistance, type of diabetes, age of onset, duration and type of therapy (Bhagoji, Mirje, Patil & Biradar, 2014).

### 1.4. Effect of T2DM on temporal resolution

The psychophysical method of threshold sensitivity and temporal encoding in auditory, touch and visuospatial were assessed. Study done by Humes et al. in year 2012 assessed higher-level of auditory processing in older adults using different paradigms such as temporal masking, gap detection threshold, and temporal-order identification tests on 14 individuals with T2DM. The result showed diabetic patient had inverse correlation on encoding of those speech (Humes et al., 2012). There are several studies reported poorer temporal resolution abilities among individuals with T2DM (McCrimmon, Deary, & Frier, 1997; Mishra et al., 2016; Pirastech et al., 2018). Study done by Mishra et al in year 2016 evaluated gap detection test (GDT) on 15 diabetes patients and compared with age matched control group in the age range of 30-40 years. They observed poor performance of the GDT abilities in diabetic patients compared to healthy individuals. They reported the poor temporal resolution abilities could be because of alteration in the central auditory system. Another study in which TMTF were assessed to find out temporal resolution abilities on 30 individuals having diabetes from minimum duration of 5 years. They obtained significant difference at the modulation frequencies i.e. 4 Hz, 8 Hz, 16 Hz, 32 Hz, 64 Hz and 128 Hz in TMTF task. They also reported that diabetic patients with high frequency hearing loss (clinical) performed significantly poorer when compared to non-diabetic group having normal hearing. The above performance probably suggesting the changes in the central auditory nervous system and widening of auditory filter in individuals with T2DM (Mishra et al., 2016). Study done by Pirasteh et al (2018) evaluated gap-in-noise test between 30 diabetes group and 30 control group with age and gender matched subjects in the age range of 25-50 years. The results showed significant difference in the mean gap-in-noise threshold between diabetics and non-diabetic patients, which indicated poorer temporal resolution abilities among diabetic patient. In a similar line, McCrimmon and colleagues also reported poor temporal and auditory processing among individuals with T2DM (McCrimmon et al., 1997). Frisina et al (2006) conducted test battery among 60 participants in the age range of 50-90 years and showed diabetes group had significant difference in the gap detection threshold, hearing in noise test and speech reception threshold than age matched control group. Further, author suggested detrimental effect of diabetes on biochemical pathways of the auditory system. Several studies reported older adults with T2DM showed poorer auditory temporal processing of speech sounds in comparison to the non-diabetic patient. They concluded that probably the outline of sensory-processing measures suggesting modality-specific auditory processing deficit instead of a modal cognitive processing problem (Humes, 2008; Humes, Burk, Coughlin, Busey & Strauser, 2007; Humes et al., 2012).

### 1.5. Effect of T2DM on SPIN

Speech perception in noise is one of the most evident difficulties reported by individuals with T2DM. Study done by Bajaj and colleagues evaluated Quick SIN (signal-to-noise ratio ranged from +20 to -10 dB) on total of 80 subjects in the age range of 28 to 60 years. The speech perception ability among individuals with greater than 5 years of diabetic age showed a poor Quick SIN scores. They signifying processing deficit at the level of central nervous system (Bajaj, Puthuchery, Bhat, & Ranjan, 2014). Studies reported poorer performance in presence of noise could be due to high frequency hearing loss (Dubno, Dirk, & Morgan, 1984; Stuart & Phillips, 1996).  Study done by Moore in 1996 reported poorer (reduced) perception of speech in presence of noise and attributed could be due to loss of audibility (Moore, 1996).While others consider temporal resolution to be a major factor in predicting speech recognition performance in noise (George, Festen, & Houtgast, 2006; Gordon-Salant & Cole, 2016; Phillips, Gordon-Salant, Fitzgibbons & Komshian, 2000). The working memory training could be applied to strengthen the participant’s speech perception in noise across languages (Ingvalson, Dhar, Wong & Liu, 2015). Millman and mattys (2016) reported that working memory related to speech perception in noise only in the least favorable SNR. Most of the studies reported the evidence on temporal resolution and speech perception in noise, limited to the younger adult population. There may be an effect of T2DM on temporal resolution abilities. Based on the above review, present study were comprehensively reporting about cognition abilities, temporal resolution abilities, and speech perception abilities in presence of adverse listening conditions among T2DM to understand functional difficulty reported in initial stages of diabetes with intact peripheral hearing acuity.

# CHAPTER 3

# METHOD

## 3.1 Research design

A static two-group comparison study was used to carry out the study

## 3.2 Participants

A total of 30 participants were included within the 50 - 60 years age range (mean age 54.76 years). Out of 30 participants, 14 individuals with T2DM having normal hearing up to 4 kHz served as clinical group and 16 individuals without T2DM with normal hearing was considered as the control group. The written informed consent was obtained after explaining the procedure and purpose of the study from all the participants.

### 3.1.1 Inclusion and Exclusion criteria

In the clinical group, the subjects who had T2DM for the duration of at least 5 years were selected. The diagnosis of the T2DM was confirmed by consultant physician based on fasting (F) and Post-prandial (PP) sugar level prior to recruiting for the study. In control group, the fasting and PP sugar level measured 2 hour after the intake of the food in plasma glucose concentration was below 100 mg/dL and 140 mg/dL respectively whereas in the clinical group the fasting and PP sugar level was greater than 126 mg/dL and 180 mg/dL respectively. In both clinical and control groups, they had normal hearing sensitivity i.e. within 25 dB HL till 4 kHz and the speech recognition threshold were in correlation with the pure tone average. They were not having any middle ear pathology as evaluated based on immittance evaluation.

The Mini-mental state examination was administered to screen cognition abilities in both the groups. The average value of MMSE score was 26.33 (maximum score = 30) for the control group whereas 27.33 (maximum score = 30) was obtained for the clinical group. The participants with PTA within 25 dB for audiometric frequencies 250 to 4 kHz were included for the study, Majority of the participants had speech identification scores >85% and the immittance finding showed 'A' or 'As' type with present or elevated reflex indicating normal middle ear functioning. In addition, those participants who had any positive history of auditory disorders like hearing loss, tinnitus and vestibular disorders, psychiatric disorders, intake of any sedative/narcotic abuse or any drugs were exempted from the research based on the structured case history along with the detailed audiological evaluation. All these evaluations confirm that above mentioned criteria's were met by all the participants.

### 3.3 Instrumentation

The below mentioned audiological equipment were used for the present investigation:

1. Calibrated dual channel Inventis Piano diagnostic audiometer was used to pure tone and speech audiometry.
2. Calibrated (GSI-Tympstar V 2.0) middle ear analyzer for evaluating tympanometry and acoustic reflexes.
3. Calibrated Biologic Navigator Pro Evoked potential (version 7.2.0.) system has been used to carry out Click evoked ABR.
4. ILO V6 was used for measuring DPOAEs.

### 3.4 Test environment

All the participants were subjected to the tests inside of an acoustically equipped room where the ambient noise level was well within the acceptable limits as specified by ANSI S3.1 (1999). Psychophysical assessments were conducted in a quiet room with good illumination, ventilation, and with minimal distraction.

### 3.5 Test Procedure

Detailed case history was obtained from each of the participant from both the groups. Otoscopic examination was performed to exclude presence of ear wax, status of tympanic membrane in both ears. Following that pure tone audiometry was done for octave frequencies ranges 250 Hz to 8000 Hz using calibrated double channel, Inventis Piano coupled to TDH-39 earphone to estimate air conduction threshold and Radio ear B-71 to find out bone conduction threshold. Using modified Hughson and Westlake procedure (Carhart & Jerger, 1959), the threshold was estimated. Threshold criteria for all the participants were fixed i.e., within 25 dB HL till 4 kHz. The speech reception threshold was obtained by using material such as spondee word list given by (Yathiraj & Vijayalakshmi, 2005). The speech identification scores were recorded by using wordlist developed by Vandana and Yathiraj (1998). The stimulus was presented in live condition at the presentation level of 40 dB SL (Ref. SRT).

Using calibrated GSI- Tympstar middle ear analyzer, immitance evaluation including both Tympanometry and acoustic reflex was done using 226 Hz probe tone from the 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz to figure out middle ear pathologies. In both control and clinical group, subjects obtained either ‘A/As ‘form of tympanogram with acoustic reflexes present at 1000 Hz and 2000 Hz. Distortion product otoacoustic emissions (OAEs) were recorded using ILO equipment. It was measured by using pure tone signals for f1 and f2 at the ratio of 1:2 and the intensity of the signal were presented at level (L1= 65, L2= 55). The amplitude of DPOAE was recorded in the 500 - 6000 Hz frequency range. The (Signal-to-noise ratio (SNR) > 6 dB) indicated presence of DPOAE. The DPOAE amplitude was more than 6 dB across frequencies in both the groups. The double channel click evoked ABR was done at repetition rate of 11.1/s and 90.1/s and presentation level at 80 dB nHL monaurally. The non-inverting electrode was positioned at Cz, inverting at earlobe/mastoid, and ground at forehead position. The electrode impedance had less than 5 kOhm. The filter setting was between 100 - 3000 Hz with rarefaction polarity. The total 1500 sweeps were recorded and it was done two times to check for the replicability of the waveform at each repetition rate.  Click evoked ABR and DPOAEs was done to rule out auditory neuropathy spectrum disorder/retro-cochlear pathology in both control and clinical groups.

### 3.6 Working memory tests

The working memory tests were assessed using Smrithi Shravan software developed by Kumar and Maruthy (2013). The stimulus were presented at 40 dB SL (Ref: PTA) using TDH-39 headphones.

*The auditory forward and backward digit span test*: The clusters of digit were presented in a random order with increasing difficulty. The set of number from 1-9 except 2 and 9 were presented and participant was instructed to type the digits in the same order or reversal by listening the number of digits. The scoring was done based on the total number of digits individuals could able to recall back. The midpoint of the last 4 trials was considered by using bracketing method for scoring. *Ascending sequencing span test:* A cluster of numbers was presented with increasing in length. The participant arranged the number from lowest to the highest order. *Descending sequencing span test:* A cluster of numbers was presented decreasing in length; the participant arranged the number from highest to lowest order. For the entire above task, the reaction time was calculated based on the number of digits repeated correctly by the participants. The midpoint of the last 4 trials was considered by using bracketing method.

### 3.7 Gap detection test

Temporal resolution abilities was evaluated by means of gap detection test, in which an ear can discriminate shortest silence over the two signals through psychoacoustics toolbox implemented in MATLAB ( Grassi & Soranzo, 2014). The standard stimulus was a Gaussian noise with no modulations. The stimulus presentation level was at 40 dB SL (Ref PTA). A 3interval alternate forced choice procedure was employed with maximum likelihood method to estimate the gap detection threshold. The subjects were instructed to identify the interval with a gap. The 750-ms Gaussian noise with varying gaps within it was used to estimate gap detection thresholds (GDT) in milliseconds. The duration of the silent gap was varied, the threshold was calculated where the minimum gap that a person could perceive was estimated.

### 3.8 Speech perception in noise test

The speech in noise was documented in terms of sentence identification scores and SNR-50 by using a custom written Matlab code. Ten sentences were presented through headphones at the most comfortable level at 60dBSPL with the different signal-to-noise ratios SNR= 0 & -5 dB SNR respectively. This was performed in the paradigm software, using programmes developed by Geetha, Kumar, Manjula and Pavan (2014). The participants were asked to respond by repeating the set of sentences. The level of the noise was varied adaptively using a one-down and one-up roving criteria to converge on the 50% point of the psychometric function. The percentage was calculated based on number of correct words repeated by the participants.

### 3.9 Statistical analysis

For analysis SPSS version 20 and SSP software was used .The Descriptive statistics was conducted in order to attain mean & standard deviation of the working memory test, temporal resolution test and SPIN test. The Shapiro-Wilk’s test was done to verify normality of the distribution and the findings showed data was not normally distributed. Hence for the statistical analysis of the data the non-parametric tests was performed, for between group comparisons Mann Whitney U test & two sample test of proportionality and was done. In order to compare outcome of all the tests Spearman correlation was performed.

# CHAPTER 4

# RESULT

The present study aimed at establishing relationship among auditory working memory, temporal resolution abilities and auditory closure deficit in type 2 diabetes mellitus (T2DM) patients. To achieve the above aim, the data was collected on 30 individuals with and without T2DM and tabulated the same. The Shapiro-Wilk's test was done to verify the normality of distribution and findings showed that data was not normally distributed ($p>0.05$). Hence, non-parametric test was done which includes Mann Whitney U test for the comparison between groups. Descriptive statistics was done to obtain mean and standard deviation (SD) for each group of the participants. Friedman test was done to check within group differences for auditory working memory. Further, Wilcoxon pairwise comparison test was done for SPIN and auditory working memory to check which pairs are different within group. In addition, spearman correlation analysis was done to see the correlation if any among auditory working memory, GDT and SPIN.

## 4.1. Auditory working memory in individuals with T2DM:

Descriptive statistics was done to obtain mean and standard deviation of the different sub-tests of auditory working memory test. The mean scores of auditory working memory test show poorer scores for T2DM individuals in comparison to non-diabetic individuals (Table 4.1). Table 4.1 shows poorer performance for T2DM individuals in comparison to non-diabetic individuals.

**Table 4.1.** *Mean and standard deviation (SD) of auditory working memory tests for control and clinical group*

| **Tests** | **Control group** | | **Clinical group** | |
|---|---|---|---|---|
| | **Mean** | **SD** | **Mean** | **SD** |
| Forward digit span | 5.02 | 1.10 | 4.75 | 1.31 |
| Backward digit span | 2.26 | 0.93 | 1.90 | 1.03 |
| Ascending sequence | 4.12 | 1.23 | 3.44 | 1.33 |
| Descending sequence | 3.21 | 1.44 | 3.29 | 1.36 |

Friedman test was done to compare different auditory working memory test scores within group. The results revealed that there is a statistically significant difference across different auditory memory test for both control group [$\chi^2_{(3)=}$ 25.47, p<0.05] as well as for the clinical group [$\chi^2_{(3)=}$ 21.30, p<0.05]. Further, Wilcoxon signed rank pair wise comparison was administered for both control and clinical group. For clinical group, Wilcoxon pair wise comparison test revealed statistical differences between different tests except between descending span versus ascending span test. Similarly, control group showed statistical significant differences across different pairs except ascending span versus forward digit span test (Table 4.2).

**Table 4.2.** : *Wilcoxon pairwise comparison test for auditory working memory tests for both control and clinical group*

| **Different pairs of auditory working memory test** | **Control group** | | **Clinical group** | |
|---|---|---|---|---|
| | **Z-value** | ***p*-value** | **Z-value** | ***p*-value** |
| Backward digit span v/s Forward digit span | -3.29 | **0.00** | -3.51 | **0.00** |
| Ascending sequence v/s Forward digit span | -1.78 | 0.07 | -2.14 | **0.03** |
| Descending sequence v/s Forward digit span | -2.51 | **0.01** | -2.35 | **0.01** |
| Ascending sequence v/s Backward digit span | -3.18 | **0.00** | -2.31 | **0.00** |
| Descending sequence v/s Backward digit span | -3.27 | **0.01** | -3.15 | **0.00** |
| Descending sequence v/s Ascending sequence | -2.82 | **0.00** | -0.69 | 0.48 |

*Note: $p<0.05$*

To analyze the differences between two groups, Mann Whitney U test was done. Results showed no statistical significant differences between groups for forward digit span [Z= -0.52; p>0.05], backward digit span [Z= -0.86; p>0.05], ascending sequence span [Z= -1.47; p>0.05] and descending sequence span test [Z= -0.11; p>0.05]. The different sub-tests of auditory working memory are also depicted in figure 4.1 with mean and 95% confidence intervals (CI).

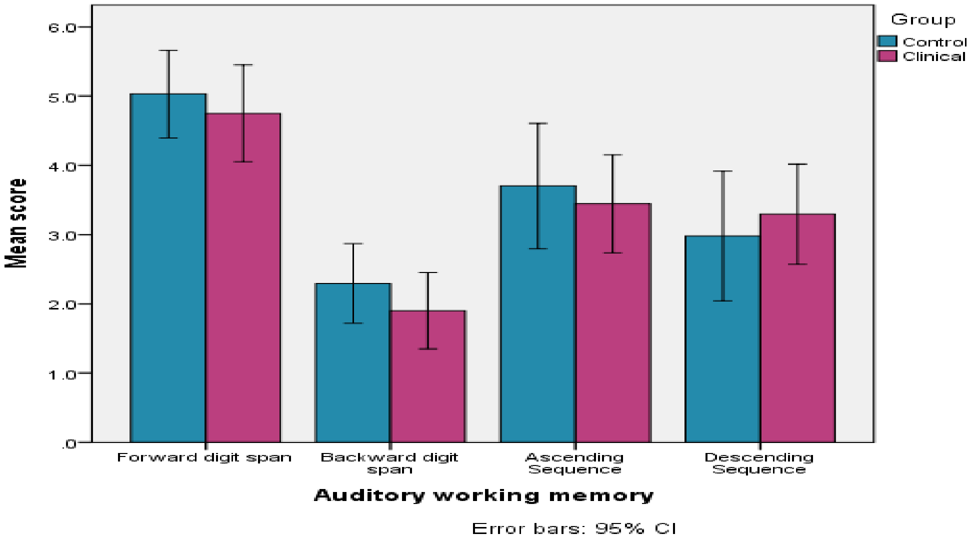

**Figure 4.1:** The graph represents different auditory working memory tests (Forward digit span, Backward digit span, Ascending sequence test & descending sequence test). Error bars represents 95% confidence intervals from the mean.

### 4.2 Temporal resolution abilities in individuals with T2DM:

Temporal resolution abilities were assessed using gap detection test in individuals with T2DM and non-T2DM. Descriptive statistics was performed to obtain mean and standard deviation for gap detection test score in control group [5.45 ms ±1.87] and in clinical group [5.27 ms ±1.69]. Further, Mann Whitney U test was done to compare between two groups and results revealed no significant difference between the two groups [Z= -0.25; p>0.05]. When individual data inspection was done for gap detection test, it was noticed that there were two individuals performance as outliers in both the groups and hence data cleaning was done. After removing the outliers, Mann Whitney U test revealed statistical significant difference between groups [Z = -2.18; $p$ <0.05]. The figure 4.2 shows the mean score with 95% CI of the gap detection threshold in both groups (Clinical & control group).

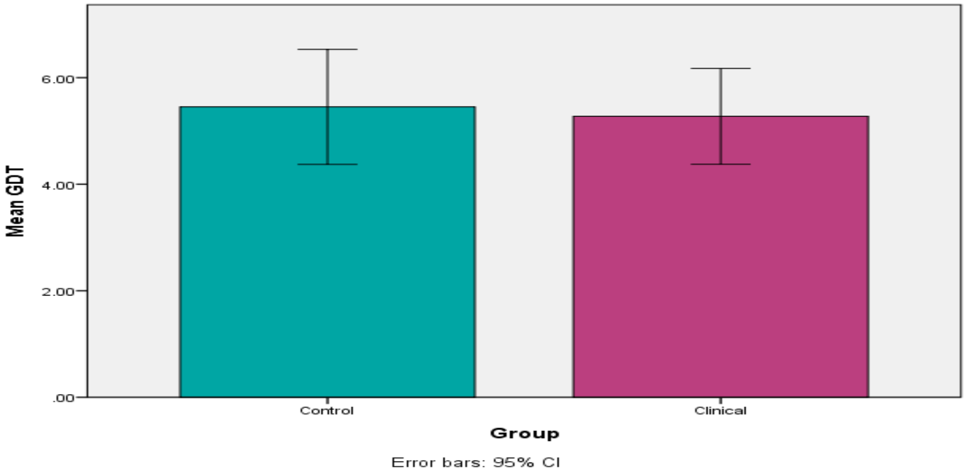

**Figure 4.2:** Comparison of mean and 95% confidence intervals of GDT score in control and clinical group for gap detection test (GDT).

### 4.3. Speech perception in noise (SPIN) in individuals with T2DM:

Descriptive statistics was done to obtain mean and standard deviation of the SPIN done at 0 dB SNR and -5 dB SNR in both groups. The mean scores of both control and clinical group were alike in performance. However, there was poorer performance noticed for both control and clinical group individuals i.e. at -5 dB SNR in comparison to 0 dB SNR (Table 4.3). Further, Mann Whitney U test was done to compare between groups and results revealed no statistical significant difference between two groups at both 0 dB SNR [Z = -0.57; p>0.05] and -5dB SNR [Z = -0.18; p>0.05]. In addition, Wilcoxon signed rank test was done to compare between two levels i.e. at 0 dB SNR and

-5dB SNR for both control and clinical group. Results showed statistical significant difference between two levels for control group [Z = -3.18; p<0.05] as well as for clinical group [Z = -3.40; p<0.05]. Figure 4.3 shows mean performance of SPIN at 0 dB SNR and at -5 dB SNR in both groups of individuals.

**Table 4.3.** *Mean and standard deviation (SD) of Speech-in-Noise test performance*

| **SPIN Test** | **Control group** | | **Clinical group** | |
|---|---|---|---|---|
| | **Mean** | **SD** | **Mean** | **SD** |
| 0 dB SNR (%) | 76.07 | 22.80 | 78.13 | 18.06 |
| -5 dB SNR (%) | 38.85 | 17.32 | 38.59 | 17.44 |

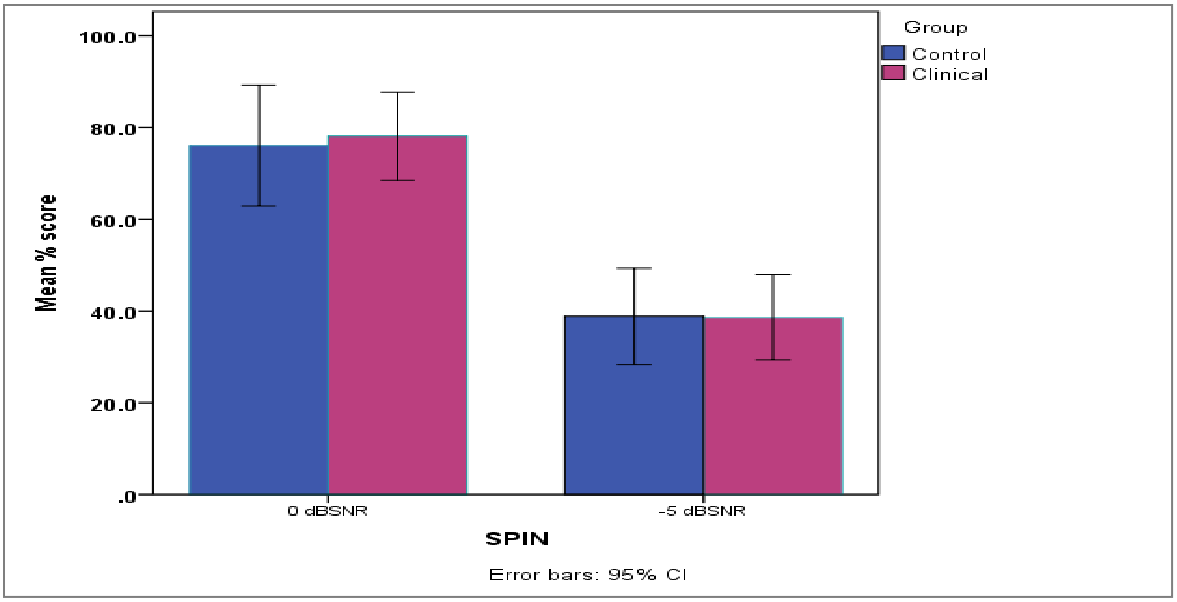

**Figure 4.3:** Mean and 95% confidence intervals of Speech perception in noise at 0 dB, -5 dB SNR in control and clinical group.

### 4.4. Relationship between auditory working memory, GDT and SPIN

The spearman correlation analysis was done to find the relationship among auditory working memory, gap detection test and speech-in-noise test performance for clinical group (Table 4.4). Results revealed that there is negative relationship between auditory working memory performance and temporal resolution tests, though it was not statistically significant. Similarly, there were negative relationship between temporal resolution abilities test and auditory closure test, though it was not statistically significant (Table 4.4). Table 4.4 indicates as GDT thresholds increases (poorer performance), both auditory working memory and auditory closure abilities reduces (poorer performance) in diabetic individuals.

**Table 4.4:** *Spearman correlation analysis performance for clinical group*

| | Fspan | Bspan | Aspan | Dspan | SPIN at 0 dB SNR | SPIN at -5 dB SNR |
|---|---|---|---|---|---|---|
| Fspan | | | | | | |
| Bspan | -0.30 | | | | | |
| Aspan | -0.25 | 0.46 | | | | |
| Dspan | -0.21 | **0.60*** | **0.66**** | | | |
| SPIN at 0 dB SNR | 0.17 | -0.10 | -0.35 | -0.23 | | |
| SPIN at -5dB SNR | **-0.54*** | **0.58*** | 0.47 | 0.13 | -0.26 | |
| GDT | 0.10 | -0.03 | -0.03 | -0.01 | -0.07 | -0.17 |

*Note: Fspan : Forward digit span; Bspan : Backward digit span; A span :Ascending sequence span; D span: Descending sequence span; SPIN: Speech perception in noise; GDT: Gap detection threshold; SNR: Signal-to-noise ratio; p>0.05.*

Since there were no significant differences noticed between two groups for auditory working memory test, temporal resolution test and SPIN test. A test of proportionality was performed to check statistical difference between two groups. Results showed even based on test of proportionality, there were no statistical significant difference between groups. The outcomes of test of proportionality with Z-value and p-value are given in the table 4.5.

**Table 4.5:** *Test of proportionality between control and clinical group*

| **Tests** | **Z value** | **P value** |
|---|---|---|
| Forward digit span | 1.43 | 0.15 |
| Backward digit span | 0.73 | 0.46 |
| Ascending sequence | 1.62 | 0.10 |
| Descending sequence | 1.09 | 0.27 |
| SPIN 0 dB SNR | 0.63 | 0.52 |
| SPIN -5 dB SNR | 0.15 | 0.87 |
| Gap detection test | 0.60 | 0.54 |

*Note: SPIN: Speech perception in noise; p>0.05.*

# CHAPTER 5

# DISCUSSION

The study aimed at establishing relationship among auditory working memory, temporal resolution abilities and speech perception-in-noise in individuals with T2DM. The auditory working memory was assessed using forward digit span, backward digit span, ascending sequence span & descending sequence span in both the groups. The temporal resolution abilities and auditory closure abilities was assessed using gap detection test and speech-in-noise test respectively.

## 5.1. Auditory working memory in individuals with T2DM

The current study shows poorer mean score for clinical group than control group in forward digit span, backward digit span, ascending & descending sequence test. However, the differences in mean scores between groups were not statistically significant. However, within group, there were statistically significant differences observed for different task of auditory working memory. The differences within group showed different levels of taxing abilities for the task used to assess the auditory working memory for each group. Whereas non-significant differences between groups could be because the clinical population had controlled diabetes since all the participants was under medication. Further, the non-significant differences between the groups could be because of less duration of the diabetes mellitus in these individuals. There are studies reported no correlation between diabetes and cognitive dysfunction (Robertson-Tchabo, Arenberg, Tobin, & Plotz, 1986; Soininen, Puramen, Hekala, Laasko, & Rikkinen, 1992; Mattler, Flack, Ronnemmaa & Hyyppa, 1985; Atiea, Moses, & Sinclair, 1995). The reason cited for either positive or negative relations could be because of widespread differences in methodology, small sample size and failure to consider non-confounding factors (Strachan, Deary, Ewing, & Frier, 1997). Studies are reported in contrast to the present study finding (Bhagoji et al., 2014; Mythri & Girish2017; Bedi & Dang, 2017). Bhagoji et al (2014) reported significant reduction in different working memory and short term memory task among diabetic individuals. They reasoned memory deficit among diabetics could be because of factors such as hyperglycemia, hypoglycemia, vascular dementia, and insulin resistance. Similar finding are reported by others researcher (Mythri & Girish, 2017; Bedi & Dang, 2017). Study done by Sommerfield and colleagues reported due to acute hyperglycemia, there is change in the performance of complex cognitive tasks and its impact on the mood and attention of the Type 2 Diabetes patients (Sommerfield & Deary, 2004). One of the reason cited in a study that poor cognitive function could be because of metabolic abnormalities (Strachan et al., 1997). Altogether, the difference between present study and above mentioned studies could be because of methodological differences, small sample size and less duration of the diabetes patient considered in the study. Further, in the present study, only five years was duration of diabetes history was considered for the selection criteria. In addition, these clinical group individuals had normal peripheral hearing, which means that the peripheral auditory system must be intact. Probably because of less duration of diabetes and normal peripheral auditory system, there were no significant differences noticed statistically between control and clinical group in the present study.

### 5.2. Temporal resolution abilities in individuals with T2DM:

Gap detection threshold mean scores were higher (poorer) in diabetic individuals in comparison to non-diabetic individuals. Further, there were statistical significant differences between groups noticed in the present study. Present study finding is in agreement with the existing literature (Mishra, Kumar & Sanju, 2016; Ehlers, 2019; Pirasteh et al., 2018). Mishra and colleagues studied temporal resolution abilities in Type 2 diabetes mellitus and reported poorer gap detection thresholds in comparison to non-diabetes group. Similarly, study done by Pirasteh and colleagues reported reduced (poorer) performance in gap-in-noise test and suggested strong association between T2DM and temporal resolution deficits. In addition, Ehlers (2019) reported poorer performance in T2DM group when compared to non-diabetes group. However, without excluding the outliers there were no statistical differences between groups for temporal resolution abilities. This could be because of controlled diabetes and not having confounding factors in the clinical group. Further, the contradictory finding in the present study could be because of the age (attributable to high frequency hearing loss), small sample size, tests reliability which may be the factor for no significant difference between the two groups. Study done by Srinivas, Shyamala & Kumar in 2016 had reported strong association between sensorineural hearing loss and diabetes mellitus in poorly controlled patients. They mentioned in those diabetic patients having HbA1c more than 8 and duration of diabetes mellitus more than 10 years are having prevalence of sensorineural hearing loss more than 85%. Whereas in present study only 2 out 15 (13.3%) were reported to have diabetes more than 10 years. In addition, no one had history of uncontrolled sugar level in the present study. This could be the reason for having temporal resolution abilities almost like non-diabetic individuals.

## 5.3. Speech perception in noise (SPIN) in individuals with T2DM:

Auditory closure abilities within group showed statistically significant differences between two different SNR i.e. 0 dB SNR & -5 dB SNR. This difference is expected in both the groups since 0 dB SNR is probably more favorable condition in comparison to the -5 dB SNR. The effect of T2DM on the speech perception in noise (0 & -5 dB SNR) was compared between control and clinical group. The result showed higher (better) score at 0 dB SNR followed by -5 dB SNR in both the groups. But no statistical significant difference in SPIN scores was observed between groups. The findings of the present study are in congruence with those reported previously in a related clinical group (Konrad et al, 2015; Çayönü et al., 2014). The study done by Konrad et al (2015) evaluated auditory function and Quick SIN on diabetes, prediabetes and control group. The result revealed poorer scores on Quick SIN in diabetes and the pre-diabetes group than control group. However, no significant differences in understanding speech in background noise and the overall scores were within normative range. They justified that the inconsistent findings could be due to lack of adequate diabetic sample & speech material (Konrad et al, 2015). Another study examined various auditory tests in elderly T2DM patients. The results showed hearing acuity is affected in diabetes group, but no significant difference in speech discrimination scores between control and clinical group. They justified the above finding could be due to physiological, biochemical complications of diabetes and limited sample (Çayönü et al., 2014). In another study done by Firsina and colleagues were reported differences in performance in pure tone thresholds, speech recognition thresholds, gap detection threshold, hearing in noise test, wide band noise thresholds, and DPOAE in T2DM than control group. However, based on the audiological tests mentioned above, study reported lesser problem at peripheral level and more damage to the central levels in T2DM. They concluded there is a severe impact of hyperglycaemic condition on the central nervous system i.e. inner ear damage in elderly hyperglycaemic patients (Frisina et al., 2006).

### 5.4. Relationship between auditory working memory, GDT and SPIN

To assess if there is any correlation among auditory working memory, temporal resolution abilities and speech perception in noise in individuals with T2DM .The present study showed no significant correlation among all the 3 test findings (Auditory working memory, GDT, SPIN). There are limited studies done on correlation findings in T2DM, while another study done in congruence to findings of the present study which was done on different sample population, Hwang and Kim (2017) compared speech perception in noise and working memory performance in normal hearing and hearing impaired individuals. They reported among normal hearing group, digit backward span as a predictor for speech perception in noise results. Further, they also suggested the ability of complex cognitive processing better explained their sentence in noise recognition difficulties. While in case of hearing impaired, they found problem in perception of speech in noise due to hearing deficits & temporal resolution deficits (Hwang & Kim, 2017). Another study reported older and younger adults with low memory capacity and normal hearing are at a disadvantage for recognizing speech in noise tokens and suggested poorer working memory capacity show difficulty to adapt for distortion of speech signals caused by background noise (Salant & Cole, 2016). In contrast to the present study, one of the study assessed effect age on auditory processing, speech perception and cognition tasks. They reported significant associations between temporal processing and speech perception, even after controlling hearing level and cognitive ability (Babkoff & Forstick, 2017). While the current findings also suggest that SPIN at -5 dB SNR is correlated to forward and backward digit span i.e. more cognitive loading process test showed correlation among complex listening task , hence more tough or complex tasks could have been applied to tap processing problem in T2DM patients. Overall, the correlation analysis results suggest all the three tests (auditory working memory, GDT & SPIN) are domain specific evaluation and not related to each other in T2DM patients.

# CHAPTER 6

# SUMMARY AND CONCLUSION

The main aim of the study was to find correlation among working memory, temporal resolution abilities and speech perception in noise (SPIN) in individuals with T2DM.The main objective was to compare test findings of auditory working memory, temporal resolution abilities and speech perception in noise (SPIN) between control and diabetes group. All the participants had no other history of hearing, mental problems. Results revealed that there is a poorer mean performance for working memory task, auditory resolution abilities, and auditory closure abilities in T2DM though it is not statistically significant. Correlation analysis showed no significant correlation among auditory working memory, temporal resolution abilities and speech perception in noise. Thus no correlation indicated independent functioning of the different test administered in the present study. Thus, to conclude, T2DM might affect complex cognitive tasks and tough or signal processing abilities at difficult situation.

## 6.1 Implications of the study

- The study may help in better understanding of any association if exists between auditory working memory, temporal resolution abilities and auditory closure abilities in individual with diabetes.
- The present study may indirectly help in designing the management strategies for individuals with T2DM.
- Add information to the literature.

### 6.2. Limitation of the Study:

- The subjective variables such as age, gender, attention, glycemic level, severity of the problem may be the compounding factor.
- Small sample size.
- The psychomotor speed of operation should have been taken care while assessing working memory**.**

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