EVALUATION OF TEMPORAL PROCESSING ABILITIES IN INDIVIDUALS CATEGORIZED BASED ON BODY MASS INDEX.

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CERTIFICATE

This is to certify that this dissertation entitled "**Evaluation of temporal processing abilities in individuals categorized based on body mass index**." is a bonafide work submitted as a part for the fulfillment for the degree of Master of Science (Audiology) of the student with Registration Number: 18AUD014. This has been carried out under the guidance of the faculty of this 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 dissertation entitled "**Evaluation of temporal processing abilities in individuals categorized based on body mass index**" 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 "**Evaluation of temporal processing abilities in individuals categorized based on body mass index**" is the result of my own study under the guidance of Dr. Prashanth Prabhu P., Assistant 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.

Mysore **Registration No: 18AUD014**

July, 2020

Dedicated to

GUIDE

and

my FAMILY

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Abstract

Obesity is a major public health problem, which is excess fat that has been accumulated in the body that might have an adverse effect on health. Many human cross-sectional studies have reported an association of poorer hearing thresholds with obesity, higher body mass index, and central adiposity. But there was a dearth of research evidence to illustrate the central auditory processing abilities in people with different body mass index individuals. Henceforth, the current study aimed to assess temporal resolution and temporal abilities in individuals categorized based on body mass index. Four groups of 10 participants in each were included based on Body mass index. Temporal processing was assessed using "mlp" toolbox which implements a maximum likelihood procedure in MATLAB. To check for temporal resolution, gap detection test, temporal modulation transfer function (8Hz, 20Hz, 60Hz, 200 Hz) and duration discrimination for complex tone were done. To check for temporal ordering, duration pattern test was done. The results indicate that the scores were poorer in underweight and obese BMI groups compared to normal and overweight BMI group. The dysfunction seen due to obesity, like lack of oxygen supply through blood, can lead to affect on peripheral and central auditory neurodegeneration and in people with underweight, maybe due to lack of macro-micro nutrients, which is needed for each cell, neurons in peripheral and central auditory system.

Chapter 1

Introduction

Obesity is a major public health problem, which is excess fat that has been accumulated in the body that might have an adverse consequence on health. Globally, obesity is one of the foremost preventable causes of death, and in the 21st century, it is one of the most serious public health problems. In 2015 in 195 countries, 100 million children, 600 million adults (12%) were obese. In women, obesity is more common than in men. Globally, recent studies have reported more than 650 million are obese, and 1.9 billion overweight adults (Ahirwar & Mondal 2018).

In India, the individuals affected by obesity are more than 135 million (Ahirwar & Mondal 2018). The prevalence will vary from rural to urban (state-wise). The prevalence of higher obesity was found to be more in the urban population and state with high socioeconomic status (Ahirwar & Mondal 2018). The prevalence varies by gender, age, socio-economic status, geographical environment. According to the National Family Health Survey (NFHS-4) 2016, the number of obese individuals has doubled in the past ten years.

WHO (2006) classifies children, adolescents, adults separately based on their age. 0-5 years is classified into children; 5- 19 years into adolescence; above 19 into the adult group.

Table 1.1

WHO (2006) classification of body mass index for adults.

BMI classification by WHO for adults.	
Underweight	< 18.5
Normal range	18.5 – 24.9
Overweight	>= 25
Preobese	25- 29.9
Obese	>=30
Obese class I	30- 34.9
Obese class II	35- 39.9
Obese class III	>40

National Institute of health and family welfare (NIHFW) by the ministry of health and family welfare (MoHFW) Government of India classification based on body mass index for adults (2016)

Table 1.2

National Institute of health and family welfare (NIHFW) by the ministry of health and family welfare (MoHFW) Government of India classification of body mass index for adults.

Weight status	BMI
Underweight	Below 18.5
Normal range	18.5 – 24.99
Overweight	More than or equal to 25
Obese	More than or equal to 30

Obesity is associated with various conditions and diseases, mainly diabetes mellitus type 2, cardiovascular diseases, osteoarthritis, asthma, metabolic syndrome, certain cancer, etc.

The possible causes for the increase of obesity are mainly due to more calories than required by the body that is the excess of calories that are converted into fat. The fat cells in adipose tissues initially increase in size later; they increase in number. Gender, age, genes, socioeconomic, psychological factors, and environmental factors may contribute to causing obesity (Haslam & James 2005).

The lifestyle is one of the most important environmental factors. The physical activity level and eating habits contribute to it. The genes responsible for metabolism, storage, and body fat distribution plays a role in deciding the body mass. Obesity tends to travel in families. There is a higher chance of being obese when one of the parents is obese. (Martinez 2000). On average, women have less muscle than men. The muscles burn more calories than any other tissues in the body. Therefore, women are likely to gain more weight than in men with the same intake of calories (Ruth et al. 1998). The metabolism tends to slow down as the age increases in older adults, thus loses muscles and gains more fat (Baum & Ruhm 2009).

1.1 Need for the study

Obesity can affect overall body functioning. It can affect our ears too. There are previous studies that have reported the damage to the ears. There are few studies that report cochlear damage leading to hearing impairment in obesity.

Curhan, Eavey, Wang, Stampfer, and Curhan (2013) studied the association between physical activity, waist circumference, and BMI. Baseline was obtained from information on BMI, physical activity, waist circumference with questionnaires. The increased risk of hearing impairment was linked with large waist circumference and higher BMI. In women, higher physical activity was linked with lesser risk of hearing impairment, whereas the increased risk of hearing impairment with larger waist circumference and higher BMI.

Kim, Won, Baek, and Yeo (2016) have studied the relation between body mass index, obesity, and hearing loss in the Korea region population. They analyzed the association between the body mass index and prevalence of the severity of hearing impairment. The results show mild to greater hearing loss are 24.9% in underweight, 20.4% in normals, 21.8% in overweight, 21.2% in obese, 24.1% in severely obese. The study concludes that there were elevated realtion of hearing loss in underweight and obese than compared with normal-weight adults based on BMI.

Scinicariello, Carroll, Eichwald, Decker, and Breysse (2019) studied the relationship of obesity with hearing loss in adolescents. The age ranging from 12 to 19 years, 2520 participants had completed audiometric data. The purpose of the study was to study the youth participants of the National Health and Nutrition Examination Survey 2007–2010, if the noise-induced, speech frequency and high-frequency hearing loss is associated with obesity. The result indicates a more incidence of notches was in females (18.2%) than in males (13.9%). The incidence of audiometric notches was higher in obese adolescents (24.8%) and normal-weight adolescents (14.7%). They conclude that the chance of reduced audition and noise-induced hearing loss can be reduced by reducing obesity.

Kim, Lalwani, Katz, and Weitzman (2013) have studied in adolescents the correlation of obesity with sensorineural hearing loss. The study was done in the US population from the National Health and Nutrition Examination Survey, 2005 to 2006. A total number of 1,488 participants age range 12 to 19 years was examined. The hearing assessment was done and defined sensorineural hearing loss as greater PTA than 15 dB. They reported that adolescents with obesity had elevated PTA threshold and had a higher prevalence of unilateral low-frequency SNHL than compared with normal-weight adolescents. Obesity was associated with an increase of 1.85-fold of sensorineural hearing loss.

Kohlberg, Demmer, and Lalwani (2018) have studied the risk of sensorineural hearing loss due to childhood obesity. They investigated form the NHANES database (2005–2010) of age range 12 to19 of the total number of 5,638 adolescents. They assessed hearing sensitivity, and anyone falling between PTA more than 15 dB HL in either of the ear was considered as sensorineural hearing loss (SNHL). They reported that the rate of sensorineural hearing loss in obese adolescents was 21.5%, and in normal-weight adolescents 13.44%. Therefore, they found out the significant trend that is the increase in obesity increases the rate of hearing loss. Thus, they can associate a higher prevalence of sensorineural hearing impairment in adolescents if they have obesity.

Croll et al. (2019) studied the association among diet value, obesity, and hearing impairment in elder adults. They have done the diet, body composition, and hearing assessment at baseline and made follow up after four years. There was an increased hearing threshold in higher body mass and fat mass index. Maintaining a healthy body composition may reduce the effect of age-related changes in hearing.

Hwang, Chen, Yang, and Liu (2012) have studied the association of pitch pattern sequence score and waist circumference in male geriatrics. A total number of 391 adults of average age 40 years were taken with normal hearing. They found that the pitch pattern sequence score was negatively associated with waist circumference. But the central obesity showed a positive correlation with atypical capability of pitch pattern sequence recognition scores. They conclude that for central auditory function, the central obesity and waist circumference as an independent risk factor.

Many human cross-sectional studies have reported an association of poorer hearing thresholds with obesity, higher body mass index (BMI), and central adiposity. Therefore, we can expect a harmful effect that can be seen in the auditory system due to obesity. The association between central auditory dysfunction and obesity has rarely been reported before. There is no attempt to evaluate temporal processing based on Body Mass Index.

Normal cochlear functioning is important for temporal processing. The dysfunction seen in peripheral hearing organs due to obesity can affect temporal processing. Temporal processing of the input auditory speech signals is important in speech perception. There are several tests under temporal processing, which include Gap Detection Test, Temporal Modulation Transfer Function (TMTF), temporal ordering and Duration discrimination for a complex tone, etc. In this study, it was attempted to evaluate temporal processing on a group of subjects with underweight, normal, overweight, and obese categorized based on body mass index.

1.2 Aim of the Study

To assess the temporal resolution and temporal ordering abilities in individuals categorized based on body mass index.

1.3 Objectives of the Study

1. To analyze the differences in gap detection threshold in individuals categorized by body mass index.

2. To analyze the differences in Duration discrimination for a complex tone in individuals categorized by body mass index.
3. To analyze the differences in Temporal-Modulation Transfer Function (TMTF) test in individuals categorized by body mass index.
4. To analyze the differences in Temporal Order for Tones test in individuals categorized by body mass index.

1.4 Null hypotheses

- There is no significant difference in gap detection threshold in individuals categorized by body mass index.
- There is no significant difference in Duration discrimination for a complex tone in individuals categorized by body mass index.
- There is no significant difference in Temporal-Modulation Transfer Function (TMTF) test in individuals categorized by body mass index.
- There is no significant difference in Temporal Order for Tones test in individuals categorized by body mass index.

Chapter 2

Review of literature

Body Mass Index (BMI) is calculated by weight in kilograms divided by height in meters squared (kg/m^2). BMI is classified into four groups that are, below 18.5 BMI is underweight, between 18.5 to 24.99 as normal and more than or equal to 25 BMI as overweight and more than or equal to 30 BMI as obese by National Institute of health and family welfare (NIHFW) by the ministry of health and family welfare (MoHFW) Government of India (2016).

Obesity is an excess fat accumulated in the body that might have an adverse effect on health. In the 21st century, obesity is a serious public health problem. The possible causes for the increase of obesity are mainly due to more calories than required by the body that is the excess of calories that are converted into fat. The fat cells in adipose tissues initially increase in size later; they increase in number. Gender, age, genes, socioeconomic, psychological factor, and environmental factors may contribute to causing obesity (Haslam & James 2005). The lifestyle is one of the most important environmental factors. The physical activity level and eating habits contribute to it. The genes responsible for metabolism, storage, and body fat distribution plays a role in deciding the body mass (Martinez 2000).

Different body mass index has a different effect on health, overweight & obese people having unhealthy fat, whereas underweight people are having less nourished. Obesity has added a higher impact on morbidity and disability than its impact on mortality (Visscher & Seidell 2001). Higher BMI is associated with increased blood pressure, which causes hypertension. Due to an increase in unfavorable lipids that is a decrease in highdensity lipoprotein (HDL) & increased low-density lipoprotein (LDL) cholesterol as high chance factor of cardiovascular disease. (Despres et al. 1988; Manson et al. 1987). Diabetes is the second leading caused of BMI related problems. One of the most expensive consequences of obesity on health is diabetes mellitus type 2 (Reaven 1988).

The higher body mass that is greater than 30 BMI has one and a half to three times higher risk of developing different cancer, most being endometrial cancer then breast, kidney, gallbladder, colon cancer following it. Osteoarthritis is also a common effect of higher body mass index, mainly in the knee, hip joints, which in turn creates more disability of a person in movement. (Oliveria et al. 1999; Heliövaara 1987). There is a risk of sleeping disorder of sleep apnea, and shortness of breath is four times more in higher BMI. (Young et al. 1993)

2.1Association of BMI and hearing loss in adults

Curhan et al (2013) studied the association between physical activity, waist circumference, and BMI. One hundred sixteen thousand four hundred thirty female nurses registered for the study, aged between 25-42 years, and excluded who reported a hearing-related problem or cancer. Baseline was obtained from information on BMI, physical activity, waist circumference with questionnaires. BMI > 40 had 1.25 RR than compared to BMI < 25. Women with waist circumference >88 cm had 1.27 RR than compared with women with waist Circumference < 71 cm. They reported that in women, larger waist and higher BMI were independently related with increased hearing loss. The RR for hearing impairment for women in the high quintile was 0.83 than compared with the low quintile of physical activity. And higher physical activity is linked with reduced risk of hearing impairment.

Kim et al (2016) have studied 61 052 subjects, the correlation between body mass index, obesity, and hearing loss in the Korea region population, which is a cross-sectional study. Subjects with any otological problems were excluded. They analyzed the relationship between the BMI and prevalence of the severity of hearing loss. According to WHO standards for Asia Pacific BMI was classified as: ,< 18.5kg/m^2 as underweight, ≥ 18.5- <22.9 kg/m^2 as normal, ≥ 23- <24.9 kg/m^2 as overweight, ≥ 25- 29.9 kg/m^2 as obese, ≥ 30 kg/m^2. Thresholds of the hearing were examined at 500, 1k, 2k, 3k, 4k, 6k Hz. The result shows mild to greater hearing loss are 24.9% in underweight, 20.4% in normal, 21.8% in overweight, 21.2% in obese, 24.1% in severely obese. The study concludes that there was high incidence of hearing loss in underweight and obese than compared with normal-weight adults based on BMI. Therefore, they conclude that there is an occurrence of hearing loss was increased as there is a decrease or increase in Body Mass Index.

Hu et al. (2019) studied the risk of hearing impairment and obesity. The baseline for 48,549 subjects age ranged between 20-60 years had confirmed no hearing loss. BMI group was classified based on WHO standards (<25, 25.0-29.9, and ≥30.0 kg/m^2). Subjects with ≥27.5 kg/m^2 had a higher probability of hearing impairment than compared with subjects with <23 kg/m^2. They found that both overweight and obese are linked with an increased risk of impaired hearing, and being metabolically unhealthy acts as an additional risk factor. They observed the maximum risk of hearing loss in unhealthy obese, following healthy obese people than the compared healthy non-obese group.

Ahmed and Ahmed (2020), examined the relation between body mass index and hearing acuity among adults in a rural community. One hundred three subjects participated in the study, they were divided into four groups according to BMI (≤18.4 kg/m² – underweight, 18.5 –24.9 kg/m² – normal, 25.0 –29.9 kg/m² – overweight and ≥30.0 kg/m² – obese). Subjects with underweight had low scores (86.4%), out of which 23.5% had moderate to profound hearing loss. They concluded that underweight adults might be at risk of hearing impairment just as evidence has shown overweight/obese adults are at an increased risk.

2. 2 Association of obesity and hearing loss in adolescents

Kim et al (2013) have studied in adolescents the relation of obesity with sensorineural hearing loss. The study was done in the US population from the National Health and Nutrition Examination Survey, 2005 to 2006. A total number of 1,488 participants age range 12 to 19 years was examined. The hearing assessment was done at 500, 1k, 2k, 3k, 4kHz, and defined sensorineural hearing loss as greater PTA than 15 dB. They reported that adolescents with obesity had elevated PTA threshold at each frequency, even as average threshold and had a higher prevalence of unilateral low- frequency SNHL (15.2%) than compared with normal-weight adolescents (8.3%). Obesity was linked with an increase of 1.85 fold of sensorineural hearing loss.

2.3 Association of Speech frequency Hearing loss and high frequency Hearing loss in obese adolescents

Scinicariello, Carroll, Eichwald, Decker, and Breysse (2019) studied the relation of obesity with hearing loss in adolescents. The age ranging from 12 to 19 years, 2520 participants had completed audiometric data, but analyzed only 1469 participants and rest were excluded. The focus of the study was to inspect the youth participants of the National Health and Nutrition Examination Survey 2007–2010, if the noise-induced, speech frequency (SFHL) and high-frequency hearing loss (HFHL) is associated with obesity. In SFHL 7.3% males, 5.4% females, in HFHL 17.9% obese, 5.4% normal BMI was the prevalence. The weighted prevalence was higher in obese than normal BMI adolescents in both SFHL and HFHL. The result indicates a higher prevalence of notches was in females (18.2%) than in males (13.9%). The prevalence of audiometric notches was higher in obese adolescents (24.8%) and normal-weight adolescents (14.7%). They conclude that the risk of hearing loss and noise-induced hearing impairment can be reduced by reducing obesity.

2.4 Association of BMI and hearing loss in children

Kohlberg, Demmer, and Lalwani (2018) have studied the risk of sensorineural hearing loss due to childhood obesity. They investigated form the NHANES database (2005–2010) of age range 12 to19 of the total number of 5,638 adolescents. Out of them, only 2,636 had valid inclusion criteria of audiometric data and BMI data. They assessed a per questioner, otoscopy, tympanometry, and hearing sensitivity, and anyone falling between PTA more than 15 dB HL in any of the one ear was considered as sensorineural hearing loss (SNHL). They reported that the rate of sensorineural hearing loss in obese adolescents was 21.5%, in overweight 16.93%, and in normal-weight adolescents 13.44%. Therefore, they found out the significant trend that is the increase in obesity increases the rate of hearing loss. Thus, it can associate the higher prevalence of sensorineural hearing loss in adolescents if they have obesity.

2.5 Association of obesity and hearing loss in older adults

Croll et al. (2019) studied the correlation between diet value, obesity, and hearing impairment in 2,906 elder adults. They have done the diet, body composition, and hearing assessment at baseline and made follow up after four years. There was an increased hearing threshold in higher body mass and fat mass index. Maintaining a healthy body composition may reduce the consequence of age-linked changes in hearing.

2.6 Association of central obesity with a low and high-frequency audiogram

Hwang, Chen, Yang, and Liu (2009) have studied the association of severity and configuration of age-related hearing impairment with central obesity. Seven hundred sixty-two subjects with symmetric SNHL and normal hearing were recruited for the study, and only 690 subjects were analyzed, by excluding otological problems. The participants' weight, height, and waist circumference were measured, and routine audiometric evaluation was done. They made two groups as obese & non-obese for both males and females as age <55 and >55 years in the study. They found the results to be significantly different in mean PTA-low with age <55 in males got 17.9 dB in the obese group and 12.8 dB in the non-obese group. In PTA-high with age > 55 in females got 26.6 dB in the obese group and 23.4 dB. They suggest that there is an association of central obesity with hearing loss, but these will differ with age and gender. They conclude that waist circumference to be one of the independent risk factors of age-related hearing impairment, particularly in males <55 years and in females > 55 years at low and high frequency.

2.7 Association of the auditory brainstem evoked potentials with obese adults.

Gupta, Gupta, and Kaitil (2017) studied brainstem auditory and visual evoked potentials in overweight and obese adults. BAEP and PRVEP were recorded in 85 healthy adults [30 (>25 BMI) obese, 30 (23-25 BMI) overweight, and 25 (<23 BMI) age and sex-matched controls] of age group 18-70 years. According to Indian-specific Body Mass Index was classified the individuals. BAEP absolute and interpeak latencies were compared among the three groups, contralateral masking was done. They report prolongation of BAEP absolute latencies III and V and interpeak latencies I-III and I-V. Thus, they conclude that there can be derangements in overweight and obese individuals, indicating CNS conduction delays with brainstem as well as cerebral cortical involvement.

2.8 Association of the auditory brainstem evoked potentials with obese children.

Unay et al. (2015) studied the auditory brainstem (BAEP) and visual evoked potentials (VEP) in children with obesity. Ninety-six children with an age range of 9-17 years were included in the study, and among them, 63 were obese, and 33 were age-gender matched control children. The amplitudes and latency of BAEP and VEP were measured in both groups. The BAEP average interpeak latency (IPL) I-III and IPL of I-V of obese were longer than the control group. To conclude, BAEP latencies were prolonged in obese compared to the healthy group. Thus, early detection of subclinical nervous system dysfunction by brainstem auditory and visual evoked potential helps to decrease the hearing-related problems.

2.9. Association of Central test: Temporal ordering in central obesity.

Hwang, Chen, Yang, and Liu (2012) have studied the association of pitch pattern sequence score and waist circumference in male geriatrics. A total number of 391 adults of average age 40 years was taken with normal hearing tested from 250 – 8 kHz each one octave. 50 sequences of 3 tone burst of 0.88 -1.43 kHz at 50 dBSL with interstimulus interval 200 ms, and with 150 ms of tone burst duration. Participants verbally repeated the sequence and recorded the response. Abnormal PPS defined as < 90%. They found that the pitch pattern sequence score was negatively associated with waist circumference. But the central obesity showed a positive correlation with atypical capability of pitch pattern sequence recognition scores. They conclude that for central auditory function, the central obesity and waist circumference as an independent risk factor.

Thus, considering all the above studies, it is clear that body mass index can have adverse effects on the auditory system. Hence, it is suggested that behavioral, temporal processing tests are assessed in individuals with different BMI.

Chapter 3

METHODS

3.1 Research design

The study was conducted as a cross-sectional study, which is a type of pre-experimental post-test only research design in which it is compared between four groups.

3.2 Sampling

The participants were selected based on Purposive Sampling, which was selected based on the body mass index.

3.3 Participants

Participants were divided into four groups based on body mass index such as 1) underweight 2) normal 3) overweight, 4) obese. In each subgroup, ten participants with age ranging from 19 to 40 years were included in the study. All participants had filled the consent form before testing, which specified the willingness of participants to take part in the study.

Subjects with <18.5 BMI were grouped into underweight, between 18.5 to 24.99 BMI grouped into normal and >= 25 BMI grouped into overweight and >= 30 BMI was categorized into obese (National Institute of health and family welfare (NIHFW) by the ministry of health and family welfare (MoHFW) Government of India 2016).

3.4 Inclusion criteria

The participants had a pure tone average of below 25 dB from 250 Hz to 4000 Hz. They had 'A' or 'As' type tympanogram with acoustic reflexes present both ipsi and contra from 500 Hz to 4000 Hz.

3.5 Exclusion criteria

Those participants who had hearing loss, those who were undergoing treatment or having any history or having diabetes, hypertension, stroke, heart disease, thyroid, polycystic ovarian disease, intellectual disability was excluded from the study. There was no history of any otological symptoms like middle ear disorders, tinnitus.

3.6 Procedure

The hearing was assessed using the conventional audiological evaluation as described below, and psychoacoustic tests of temporal processing assessed through the psychoacoustics toolbox implemented in MATLAB.

3.6.1 Detailed Case History

Participant's demographic data and detailed case history were taken in a structured interview. Information about auditory disorders like hearing loss, middle ear disorders, tinnitus, and vestibular disorders like vertigo and exposure to noise exposure was taken. Information of any disorders or any syndrome was included in the case history. If these problems were present, then these participants were excluded and, if not present, were included in the study.

3.6.2 BMI

Each participant's height in meters and weight in kilograms was measured. BMI was calculated by weight in kilograms divided by height in meters squared (kg/m^2).

3.6.3 Otoscopy

To visualize the ear canal and tympanic membrane, otoscopy was carried out to each participant. Those with excessive cerumen and other abnormality were referred for further medical management.

3.7 Test environment

All the participants were subjected to the tests in an acoustically treated room where the ambient noise level is within the permissible limits as specified by ANSI S3.1 (1999-R2013).

The equipment that was used in the study were audiometer, immittance meter, otoscope, and laptop in which MATLAB software was installed. Appropriate instruction was given to each individual before testing each test.

3.8 Pure tone audiometry

All participants were subjected to pure tone audiometry for octave frequencies between 250 to 8000 Hz for air conduction and 500 to 4000 Hz for bone conduction using modified Hughson and Westlake procedure (Carhart & Jerger 1959) with a calibrated dual-channel diagnostic audiometer in a sound-treated room. To rule out the presence of any peripheral hearing loss in the participants, criteria of 25 dB HL pure tone average of 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz was considered.

3.9 Immittance measurements:

Immittance evaluation, which included both tympanometry and acoustic reflexes, was done to identify any middle ear dysfunction. Acoustic reflex using a 226 Hz probe tone at 500 Hz, 1000 Hz, 2000 Hz, & 4000 Hz was done ipsilaterally and contralaterally.

3.10 Psychoacoustic Tests of Temporal Processing

Temporal processing tests were assessed through the psychoacoustics toolbox implemented in MATLAB (Grassi & Soranzo 2014), at 30 dB SL, through maximum likelihood procedure (mlp) except for temporal ordering that is duration pattern test which will be tested using CD in laptop.

3.10.1. Gap detection

The temporal resolution task was assessed by the Gap detection test, in which ear can discriminate the shortest silence over the two signals. A three interval three alternate forced procedure was used with a two-down one-up roving criteria. The standard stimulus used was a Gaussian noise with no modulations. To estimate GDT, the participants were instructed to specify 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 noise has 0.5ms cosine ramps at the beginning and end of the gap. The duration of the silent gap was varied according to the listener's act, and the minimum gap that a person can perceive was estimated.

3.10.2. Duration discrimination for a complex tone

The duration discrimination test assesses temporal resolution abilities. In this test, the tone had four harmonics (f0 =330 Hz, mi4). The tone had raised the onset and off gates of 10ms. The participants identified the longest tone in a three alternative forced-choice (3AFC) method.

3.10.3 Temporal-Modulation Transfer Function (TMTF)

The temporal modulation transfer function is the ability of the ear to detect temporal modulation in the complex acoustic signal, and TMTF is obtained by a sinusoidal amplitude modulated signal. A 500ms Gaussian noise was sinusoidally amplitude modulated at 8Hz, 20Hz, 60Hz, 200Hz. The depth of the modulation was expressed in modulation index that ranges from 0.0 that is no modulation to 1.0 that is full modulation, which can be referred to as 100 % modulation applied to the noise carrier signal.

On each trial of three blocks, two blocks had standard unmodulated stimuli and others with a sinusoidally amplitude-modulated target signal. The participants identified which interval had the modulated noise in a three interval three alternative forced-choice method. The order of presentation of the stimuli was randomized.

3.10.4 Temporal Ordering using Duration pattern test

This test assesses the temporal ordering. The duration pattern test was tested in the manner described by and Gouri (2003). A 1000 Hz, pure tone with two different durations (i.e., short 250 msec and long 500 msec), was used as the stimuli. By merging these two durations in three-tone patterns, six different patterns were generated (Long Long Short, Long Short Short, Long Short Long, Short Short Long, Short Long Long, Short Long Short). The interstimulus interval was 250 msec within a tone sequence and 6 sec between two-tone sequences. Following practice trials, 30 test items were administered. Participants were asked to repeat the order vocally.

Chapter 4

Results and Discussion

In the study, based on Body Mass Index (BMI) that is normal, underweight, overweight and obese, 10 participants were included in each group. For all the groups, temporal processing was assessed using "mlp" toolbox, which implements a maximum likelihood procedure in MATLAB. The entire test was done using "mlp" tool box except for temporal ordering. Temporal ordering was checked using a duration pattern test, which was carried out using the test CD and was ran on a laptop. The data obtained were analyzed using the statistical package of social science (SPSS) software version 20.0. Shapiro Wilk test of normality was administered to check whether the data is normally distributed or not and was found to be normally distributed ($p>0.05$). Hence, parametric inferential statistics were done. One way ANOVA was administered for between-groups comparison.

The results of the study are explained under the following headings:

4.1 Comparison of gap detection test in individuals with different body mass index

4.2 Comparison of Duration discrimination for a complex tone in individuals with different body mass index

4.3 Comparison of Temporal-Modulation Transfer Function (TMTF) test in individuals with different body mass index

4.4 Comparison of Temporal Order for Tones test in individuals with different body mass index.

4.1 Comparison of Gap detection test (GDT) in individuals with different body mass index

Mean, median, range, and standard deviation (SD) of gap detection test in individuals with different body mass indexes are shown in Table 4.1. The data showed the difference between the BMI categories, which indicates a lesser mean score that is better performance for the normal and overweight BMI groups when compared to underweight and obese BMI groups.

Table 4.1

Mean, Median, and Standard deviation (SD) scores of gap detection test in individuals categorized by body mass index.

	Normal	**Underweight**	**Overweight**	**Obese**
Mean	1.96	2.09	1.94	2.03
Median	1.81	2.10	1.95	2.00
Std. Deviation	0.44	0.30	0.27	0.20
Range	1.49	1.08	0.91	0.61
Minimum	1.31	1.62	1.48	1.78
Maximum	2.8	2.7	2.39	2.39

The gap detection test scores were compared between individuals with different body mass index using the one way ANOVA. It revealed no significant difference between the groups [F(3, 39) = 0.45, p>0.05). The mean and standard deviation of gap detection test scores for all the groups have been represented in figure 4.1.

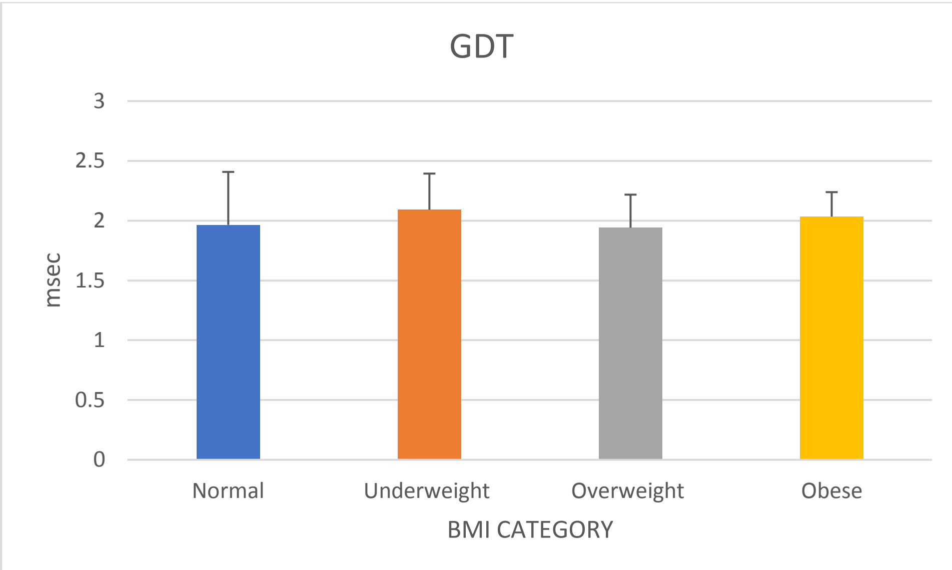

Figure 4.1 Mean and standard deviation (SD) of gap detection in individuals categorized by body mass index.

4.2 Comparison of Duration discrimination for a complex tone in individuals with different body mass index.

Mean, median, range, and standard deviation (SD) of Duration discrimination for a complex tone in individuals with different body mass indexes are shown in Table 4.2. The data showed the difference between the BMI categories, which indicates lesser mean scores that are better performance for the normal, overweight, and obese BMI groups when compared to the underweight group.

Table 4.2

Mean, Median, and Standard deviation (SD) scores of Duration discrimination for a complex tone in individuals categorized by body mass index.

	Normal	**Underweight**	**Overweight**	**Obese**
Mean	51.17	56.47	50.25	51.51
Median	49.24	57.98	46.66	54.44
Std. Deviation	19.50	14.79	16.89	11.47
Range	68.35	40.30	54.57	36.07
Minimum	29.29	40	29.29	30.9
Maximum	97.64	80.3	83.86	66.97

The duration discrimination for a complex tone score were compared between individuals with different body mass index using the one way ANOVA. It revealed no significant difference between the groups [F(3, 39) = 0.3, p>0.05). The mean and standard deviation of duration discrimination for a complex tone score for all the groups have been represented in figure 4.2.

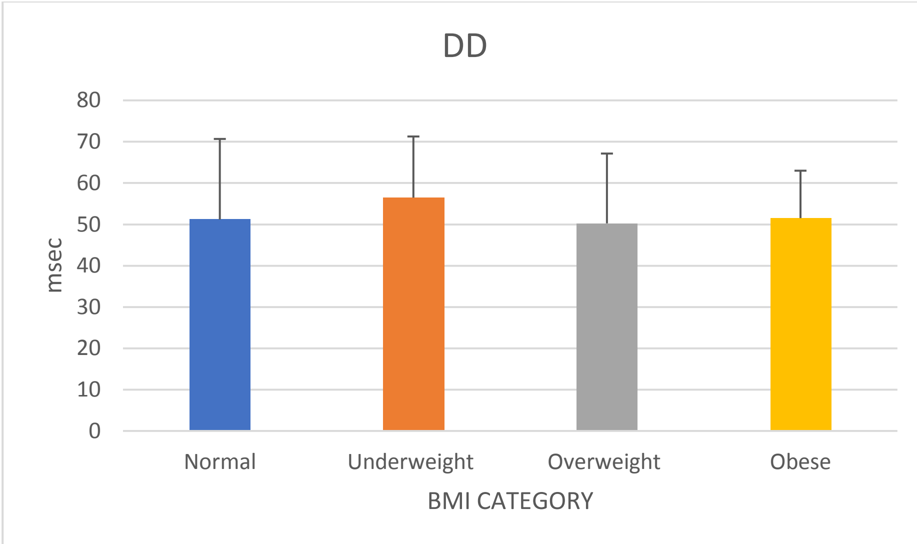

Figure 4.2 Mean and standard deviation (SD) of duration discrimination for a complex tone in individuals categorized by body mass index.

4.3 Comparison of Temporal-Modulation Transfer Function (TMTF) test in individuals with different body mass index

Mean, median, range, and standard deviation (SD) of Temporal-Modulation Transfer Function test in individuals with different body mass indexes are shown in Table 4.3. The data showed a difference in SAM 8 Hz between the BMI categories, which indicates poorer scores for the underweight group when compared to the normal, overweight, and obese BMI groups.

Table 4.3

Mean, Median, and Standard deviation (SD) scores of Temporal-Modulation Transfer Function (TMTF) tests at four frequencies (8 Hz, 20 Hz, 60 Hz, 200 Hz) in individuals categorized by body mass index.

Group	TMTF	8 Hz	20 Hz	60 Hz	200Hz
Normal	Mean	-33.38	-37.39	-35.22	-25.63
	Median	-34.25	-38.37	-35.17	-26.77
	SD	1.28	2.11	2.69	2.37
	Range	3.00	5.60	6.95	6.00
Underweight	Mean	-30.84	-34.48	-33.81	-23.30
	Median	-31.40	-33.82	-34.17	-22.80
	SD	3.42	3.14	3.50	2.85
	Range	8.70	8.40	10.50	8.35
Overweight	Mean	-34.11	-34.27	-33.78	-26.28
	Median	-34.25	-36.10	-34.12	-26.85
	SD	.95	6.40	2.34	1.75
	Range	3.81	20.65	7.35	5.70
Obese	Mean	-33.57	-36.27	-32.95	-23.89
	Median	-34.25	-36.10	-33.82	-25.35
	SD	1.50	2.43	5.33	4.29
	Range	4.30	6.34	15.05	14.40

The Temporal-Modulation Transfer Function (TMTF) test was compared between individuals with different body mass index using the one way ANOVA. It revealed no significant difference between the groups except in SAM 8 Hz.

For 8Hz, [$F(3, 39) = 5.14$, $p<0.05$)]; For 20Hz, [$F(3, 39) = 1.45$, $p>0.05$)]; For 60Hz [$F(3, 39) = 0.66$, $p>0.05$)]; For 200Hz [$F(3, 39) = 2.24$, $p>0.05$)]

Further, the Sidak Post hoc test was done to compare SAM 8 between the groups, and it revealed that the scores were significantly poorer for underweight compared to overweight and normal and obese BMI groups. The mean Temporal-Modulation Transfer Function (TMTF) test at four frequencies (8Hz,20Hz, 60Hz, 200Hz) scores for all the groups has been represented in figure 4.3.

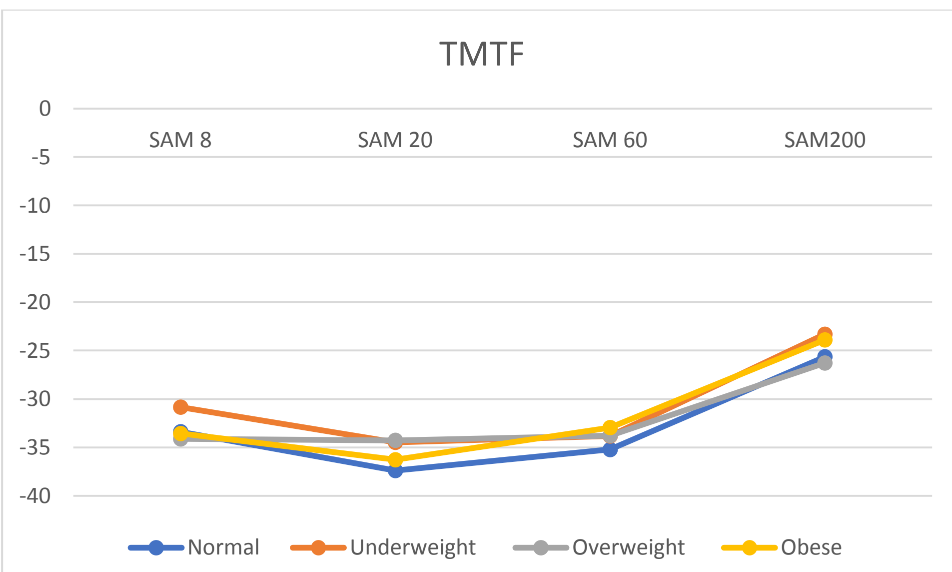

Figure 4.3 Mean of Temporal-Modulation Transfer Function (TMTF) test of SAM 8Hz, SAM 20Hz, SAM 60Hz, SAM 200Hz frequency in individuals categorized by body mass index.

4.4 Comparison of Temporal Order for Tones test in individuals with different body mass index.

The mean, median, range, and standard deviation (SD) of Temporal Order for Tones test (Duration Pattern Test) in individuals with different body mass indexes are shown in Table 4.4. The data showed a difference between the groups, which indicated lesser mean scores for the underweight and obese BMI groups compared to normal and overweight BMI groups.

Table 4.4

Mean, Median and Standard deviation (SD) scores of Temporal Order for Tones test (Duration Pattern Test) in individuals with different body mass index.

	Normal	Underweight	Overweight	Obese
Mean	97.64	92.64	96.30	90.31
Median	98.30	93.30	96.60	90.00
Std. Deviation	2.76	5.17	3.31	4.55
Range	6.70	16.70	10.00	16.60
Minimum	93.3	83.3	90	80
Maximum	100	100	100	96.6

The Temporal Order for Tones test (Duration Pattern Test) scores was compared between individuals with different body mass index using the one way ANOVA. It revealed significant difference between the groups [$F(3, 39) = 6.8, p<0.05$)]. Further, Sidak Post hoc test was done to compare between the groups, and it revealed that the scores were significantly poorer for underweight and obese BMI groups compared to overweight and normal BMI groups. The mean temporal order for tones test (Duration Pattern Test) scores for all the groups have been represented in figure 4.4

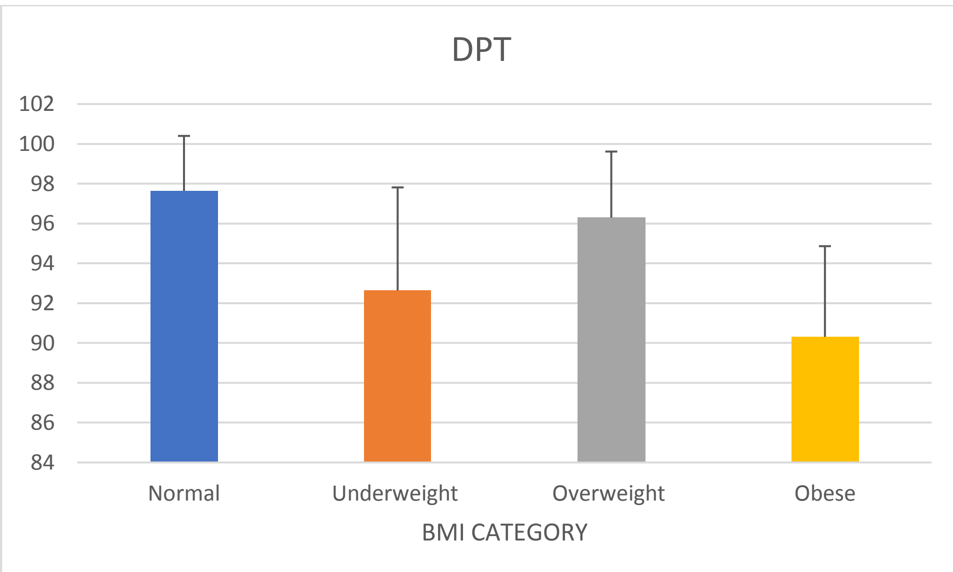

Figure 4.4 Mean and standard deviation (SD) of Temporal Order for Tones test (Duration Pattern Test) in in individuals with different body mass index.

Temporal processing of the auditory input signals supports in recognizing the phonetic elements in the speech, which helps in speech perception. The problems found in the temporal processing have been noted to hinder the normal phonemic and speech recognition. (Amaral et al. 2014). Some of the studies have evaluated the effect of obesity on peripheral hearing like peripheral, age-related, high-frequency and sudden sensorineural hearing loss, etc. But there is a lack of research evidence to explain the temporal processing in individuals with overweight and obesity. Therefore, the current study was aimed to evaluate temporal processing (temporal resolution, temporal ordering) abilities in individuals categorized based on body mass index.

People with healthy and unhealthy obese has a high risk of hearing impairment than compared to people with non-obese. Thus, they suggest that obesity is an alone risk factor of hearing impairment and unhealthy metabolic as an additional risk factor (Hu et al. 2019). In another cross-sectional study analysis, they found higher BMI and adiposity is related to higher increased hearing thresholds. (Croll et al. 2019).

Typically, individuals with overweight and obesity comprise more adipose tissue, which is a part of energy homeostasis, and also responds to the nutrient, hormonal signals, immunity, neural and neuroendocrine function. Thus, adipose tissue has complex interactions with peripheral organs and the brain (Ahima 2006). People with obese secretes low protein adiponectin plasma levels by adipose tissues, which is linked with a 2-fold increase of high-frequency hearing loss, which in turn affects the auditory system in comprehending speech clearly (Hwang et al. 2011; Kim et al. 2013)

Obesity is related to increased oxidative stress (Furukawa et al., 2017). It is linked with the production of reactive oxygen species, which are consequences in damaging multiple cells, and cochlear inner hair cells are also targets in accelerating aging processes. And due to oxidative stress and obesity, induced inflammation may contribute to hearing loss (Dhanda & Taheri 2017).

Cochlea requires good oxygen supply by the rich vascular source from the link of capillaries and tissues will have an effect on the integrity of inner hair cells. Thus, a deficiency of blood flow to stereocilia can give rise to the risk of hearing impairment from obesity. Mechanism of hearing loss in obese is that due to vasoconstriction to the inner ear, which is a mechanical strain on capillary walls produced by adipose tissue. Once the inner hair cells are damaged, the regeneration is not possible and causes permanent hearing loss. (Curhan et al. 2013; Dhanda & Taheri 2017). Thus, the damage to the cochlea could have affected the temporal processing abilities in individuals with obesity.

Hwang, Hsu, Yu, Liu, and Yang (2013) studied a histopathology study of the cochlea between diet-induced obesity (DIO) CD/1 mice group and control mice group at the beginning of 4^{th} week and at the end of 20^{th}week. They identified that in DIO group had more body-weight, increased concentration of fasting plasma triglyceride, and higher omental fat mass than compared to the control group. DIO group also had small diameter vessels, and stria vascularis had thicker walls at the middle & basal turn of the cochlea. In spiral ligament & spiral ganglion the cell densities were lower at basal turn of cochlea in DIO group. The brainstem evoked auditory response thresholds in DIO group were significantly higher at high frequencies than the control group. They found that DIO group had hearing degeneration via cell loss in spiral ganglion & spiral ligament, increased hypoxia and cell deaths related with stimulation of caspase dependent & independent apoptosis signaling pathways in CD/1.

The dysfunction seen due to obesity, like lack of oxygen supply through blood, can lead to hypoxia, oxidative stress, ischemic damage, cell injury, mitochondrial dysfunction, and finally, can effect on peripheral and central auditory neurodegeneration.

(Yamasoba et al. 2013). Normal cochlear and neural functioning is important for auditory temporal processing. When both or either peripheral or central auditory system is affected then can affect temporal processing.

The underweight adults had higher hearing thresholds, so they may be at risk of hearing impairment. The explanation given was due to malnutrition, and thus they recommend more attention towards dietary, food supplementation, and education to the community regarding nutritional facts. (Ahmed & Ahmed 2020). Nutrients like vitamins A, C, E, magnesium (Tamir et al. 2010); vitamin B12 (Houston et al. .1999) and b-carotene, folate, b-cryptoxanthin (Curhan et al. 2015) gives protection from hearing loss and are linked with a lesser risk of hearing impairment. These nutrients lack may contribute to central auditory dysfunction, which can affect temporal processing. Therefore, by intaking these foods with nutrients can provide antioxidative and vascular benefits which protect hearing. (Muurling & Stankovic 2014).

Hwang, Chen, Yang, and Liu (2012) studied the association of pitch pattern sequence score and waist circumference in 391 male geriatrics with normal hearing. The central obesity showed a positive correlation with atypical ability of pitch pattern sequence recognition scores. They conclude that for central auditory function, the central obesity and waist circumference as an independent risk factor. The contribution of obesity to central auditory dysfunction is maybe through similar mechanisms of peripheral hearing loss and or maybe indirectly through its comorbidities.

As there is a tendency towards an rise in hearing loss in obesity, screening for obesity can help people who are undiagnosed and untreated for hearing loss. (Kohlberg, Demmer & Lalwani 2018). Children with hearing loss are likely to have speech & language, behavioral problems, and academic difficulties than compared to children with normal hearing. Awareness should be created in patients with obesity about the increased risk of hearing problems. Preventive efforts must be taken to reduce obesity and to diminish the risk of hearing loss are required. (Scinicariello et al. 2019). For the short term period at least, by losing the weight, it has been shown that to improve lipid levels and blood pressure. (Visscher & Seidell 2001). To prevent hearing loss, a major role is to improve metabolic health and control of obesity. (Hu et al. 2019).

In the framework of this study, the temporal resolution and temporal ordering abilities in individuals categorized based on body mass index were assessed. In the gap detection threshold, duration discrimination for a complex tone, temporal-modulation transfer function test (TMTF), temporal order for tones test, better performance was seen in normal body mass index (BMI) group than underweight, overweight and obese BMI group because of good healthy peripheral and central auditory system. In obese subjects' BMI group, they had poor scores in the gap detection threshold, TMTF, temporal order for tones test than compared to other BMI groups. This is reasonably due to changes in cochlear and neural changes happening in individuals with obesity thus would have poor temporal coding, reduced frequency selectivity, and trouble in responding to rapid change in stimuli. In underweight subjects, BMI group, the gap detection threshold, duration discrimination for a complex tone, TMTF test, temporal order for tones test had poor scores may be due to lack of macro-micro nutrients, which is needed for each cell, neurons in the peripheral and central auditory system.

Chapter 5

Summary and conclusions

Obesity is a main public health problem, which is an excess fat that has been accumulated in the body that might have an adverse consequence on health. Globally, studies have reported more than 650 million are obese, and 1.9 billion overweight adults. In India, the individuals affected by obesity are more than 135 million (Ahirwar & Mondal 2018). Many human cross-sectional studies have reported an association of poorer hearing thresholds with obesity, higher body mass index, and central adiposity (Curhan, Eavey, Wang, Stampfer, & Curhan 2013; Scinicariello, Carroll, Eichwald, Decker & Breysse 2019). But there was a dearth of research evidence to illustrate the central auditory processing abilities in people with different body mass index individuals. Henceforth, the current study aimed to assess temporal resolution and temporal abilities in individuals categorized based on body mass index. The differences in gap detection threshold, duration discrimination for a complex tone, and temporal-modulation transfer function, temporal order for tones test in individuals categorized by body mass index was analyzed.

Participants in the age range of 19 to 40 years were divided into four groups (10 subjects in each group) based on body mass index such as 1) underweight <18.5 BMI, 2) normal between 18.5 to 24.99 BMI, 3) overweight >= 25 BMI, 4) obese >= 30 BMI (National Institute of health and family welfare (NIHFW) by the ministry of health and family welfare (MoHFW) Government of India 2016). All the participants were subjected to otoscopy, pure tone audiometry, and immittance measurements to check for hearing sensitivity within normal limits. BMI was calculated by weight in kilograms divided by height in meters squared (kg/m^2) to each participant. Psychoacoustic tests of temporal resolution i.e. gap detection test (GDT), duration discrimination for a complex tone (DDT), and temporal modulation transfer function (TMTF) at 8 Hz, 20 Hz, 60 Hz and 200 Hz were administered using MATLAB with mlp toolbox (Grassi & Soranzo, 2014), at 30 dB SL, through maximum likelihood procedure (mlp) except for temporal ordering that is duration pattern test which was tested using CD in laptop.

The data obtained were analyzed using the statistical package of social science (SPSS) software version 20.0. Shapiro Wilk test of normality was administered to check whether the data is normally distributed or not and was found to be normally distributed ($p>0.05$). Hence, parametric inferential statistics were done. One way ANOVA was administered for between-groups comparison. The results showed that the scores were poorer in underweight and obese groups compared to the normal and overweight group but not significant. The dysfunction seen due to obesity, like lack of oxygen supply through blood, can lead to hypoxia, oxidative stress, ischemic damage, cell injury, mitochondrial dysfunction, and finally, could have an effect on peripheral and central auditory neurodegeneration. (Yamasoba et al. 2013) and in people with underweight, maybe due to lack of macro-micro nutrients, which is needed for each cell, neurons in the peripheral and central auditory system. Thus, the study suggests that reduced BMI and increased BMI may affect temporal processing abilities. This is supported by previous studies which also report poor auditory performance in individuals with higher body mass index (Curhan, Eavey, Wang, Stampfer, & Curhan 2013; Scinicariello, Carroll, Eichwald, Decker & Breysse 2019) and with lower body mass index (Ahmed & Ahmed 2020).

5.1 Clinical implications

- The study helps in better understanding of temporal resolution and temporal ordering ability in individuals with different categorized body mass index that is underweight, overweight, and obesity.
- Hearing screening for underweight and obese people can be done to reduce further risk by early detection of peripheral and central hearing problems.
- Early identification of academic difficulties due to central auditory dysfunction in school going children with underweight and obese can be tested by temporal processing tests.
- Body mass index can be added in the case history sheet to add as a risk factor.
- It can further help to counsel regarding the adverse auditory effects because of abnormal body mass index.

5.2 Limitations of the Study

- The larger sample size could have been included, to generalize.
- The exercise and its number of hours done by each subject could have been studied, which can be a variable.
- Attention and mood of each subject could have affected the tests.

5.3 Future directions

- A large number of subjects can be studied so that it can be generalized.
- Temporal processing can be assessed in children with different body mass indexes, which helps in early identification.
- To study temporal fine structure processing and working memory in individuals with body mass index.

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