# DPOAE INPUT OUTPUT FUNCTION IN

# INSTRUMENTAL MUSICIANS

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MAY, 2019

## CERTIFICATE

This is to certify that this dissertation entitled **'DPOAE input output function in instrumental musicians'** is a bonafide work submitted in part fulfilment for degree of Master of Science (Audiology) of the student Registration Number: 17AUD021. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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# CERTIFICATE

This is to certify that this dissertation entitled **'DPOAE input output function in instrumental musicians'** has been prepared under my supervision and guidance. It is also been 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 **'DPOAE input output function in instrumental musicians'** is the result of my own study under the guidance a faculty at All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru,
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## Abstract

***Background:*** *Music is a form of art and it plays an important role in human culture. Musical training has shown to deteriorate hearing status of professional musicians***.** *Distortion Product OAEs (DPOAEs) are produced when two tones interact on the basilar membrane. DPOAE input output function can be an indicator of non-linear functioning of cochlea.*

***Aim:*** *The aim of this study was to evaluate DPOAE input-output function in musical instrumental users.*

***Method:*** *A total of 20 individuals without formal musical training were taken in the age range of 18-35years and 40 individuals with formal musical training were taken along with subcategorization as percussion instrument users, string instrument users, membranophone instrument users and wind instrument users. DPOAE I/O function was performed and slope and area of the DPOAE I/O function was compared at different frequencies and effect of frequency on the same.*

***Results:*** *The results of Mann-Whitney U test revealed significant difference in slope and area of DPOAE I/O function in individuals with and without formal musical training. Frequency had significant effect on slope and area of DPOAE I/O function in both the groups. There was no significant difference in slope and area of DPOAE I/O function among subcategory of instrumental users.*

***Conclusion:*** *The increased steepness of the slope and increased area of DPOAE I/O function indicates a relatively better functioning of the cochlea in instrumental users. Musicians need to be counselled about both positive and negative effects of music on their hearing abilities. Since long term exposure may lead to deterioration in hearing as evidenced through previous literature, musicians need to be counselled regarding usage of ear protective devices as well.*



***Key words:*** *Distortion product otoacoustic emissions, musical abilities, input/output function*

# Chapter 1

# Introduction

Music is a form of art and it plays an important role in human culture. Each professional musician will spend many hours in playing and practicing instrument individually and/or as a team member in different groups. Hearing plays a vital role in musicians. According to Axelsson, and Lindgren (1981), important ‘instrument’ is sense of hearing which needs to be taken care, to protect the auditory sense for maintaining perception of music.

Studies on effect of music on auditory system have been done extensively (Axelsson & Lindgren, 1981; Karlsson, Lundquist, & Olaussen, 1983; Johnson, Sherman, Aldridge, & Lorraine, 1986; Early & Horstman, 1996). Musicians are more prone to get affected because of high levels of noise during their practice and performance (Early & Horstman, 1996). Musicians perform for 4-8 hours per day (Sataloff & Sataloff, 1993). Musicians are still at risk for suffering from the effects of NIHL even though their exposures are intermittent, because of high levels of sound produced by instruments. Based on method of sound production, musical instruments are divided into i) percussion, ii) string, iii) membranophones iv) wind instruments (Flora, 1999). Folprechtova and Miksovska (1981) measured sound levels of 92 dB (A) with variations of 87-98 dB (A) in a symphony orchestra. They reported the sound levels of various instruments, as shown in Table 1.

Table 1.1

*Reported the sound levels of various instruments (Folprechtova & Miksovska, 1998)*

| Instrument | dB (A) |
|---|---|
| Violin | 84-103 |
| Cello | 84-92 |

| | |
|---|---|
| Piccolo | 95-112 |
| Flute | 85-111 |
| Clarinet | 92-103 |
| French Horn | 90-106 |
| Oboe | 80-94 |
| Trombone | 85-114 |
| Xylophone | 90-92 |

Occupational Safety and Health Administration (OSHA) in 1983 gave safety regulations for sounds exceeding 90 (A) dB average over an eight hour work. Sound levels measured during live concerts and practice sessions vary from 102.5 dB (A) to 106 dB (A), which exceeds the safety limits. Musicians complain about diplacusis, hyperacusis and tinnitus along with hearing loss (Dinakaran, Ruth, & Rejoy, 2018). Walbrzych (2010) assessed the risk of noise induced hearing loss due to noise exposure in orchestral musicians. The study found that the classical orchestral musicians are usually exposed to sound at equivalent continuous A-weighted sound pressure levels of 79 - 90 dB, for 20 - 45 hours per week and such high exposure to high levels over 40 years of employment might cause the risk of hearing impairment in the range of 16 - 43% and 4 - 30% in case of males and females, respectively. The study reported that the highest risk is related to playing a clarinet (up to 35%), tube (up to 35%), trumpet (up to 40%), percussion section (up to 41%) and horn (up to 43%).

Otoacoustic emissions (OAE) provide an index of cochlear function and are linked to outer hair cell health (Kemp, 2002). Damage to cochlea can be found through DPOAEs. The sound induced vibrations by the OHCs in the cochlea which are by-products of compressive non-linear amplification, which enhances both the frequency resolution of hearing and sensitivity are referred to as DPOAEs (Robles & Ruggero, 2001; Moore, 2007). DPOAEs are dependent on presentation level of the tones, and an input/output (I/O) function can be obtained by keeping the stimulus frequency and frequency ratio constant. The input-output function slope obtained for different input levels is directly reliant on cochlear health and therefore gives a picture of the supra-threshold non-linear characteristics of the cochlea. The level-dependent growth of the DPOAE as depicted by an input/output (I/O) function provides a way for indirect metric of cochlear compressive nonlinearity and is similar in gross form to that measured directly from the basilar membrane of laboratory animals, most notably at the peak of the traveling wave (Ruggero, Rich, Recio, Narayan, & Robles 1997; Robles & Ruggero 2001); it is also similar to compression inferred from human perceptual data (Boege & Janssen 2002; Johannesen & Lopez-Poveda, 2008; Rasetshwane, Neel, Kopu, & Gorga, 2013).

Input-output functions of Distortion product otoacoustic emission is characterized by steep growth at low stimulus levels and amplitude saturation at moderate-to-high levels (Abdala 2000; Neely, Gorga, & Dorn, 2003; Gorga, Neely, Dorn, & Hoover, 2003). A truncated I/O function is shown by hearing-impaired ears, because of increase in the DPOAE threshold, an extended region of monotonic growth, and slightly steeper slope of DPOAE growth beyond the compression threshold (Dorn et al, 2001).

Features measured from DPOAE I/O function have shown to correlate with perceptual measures of compression such as temporal masking curves and categorical loudness scaling (Williams & Bacon, 2005; Johannesen & Lopez-Poveda, 2008), suggesting they can provide objective measures of perceptual phenomena. In impaired ears, the slope of the I/O function was steeper (Dorn, Konrad-Martin, Neely, Keefe, Cyr, & Gorga, 2001). Weighted extrapolation I/O functions of DPOAE can be used as a valuable clinical tool for the objective assessment of cochlear hearing loss as there is high correlation and relatively small differences between objectively estimated DPOAE threshold and subjectively determined hearing threshold of pure-tone audiograms (Oswald & Janssen, 2003).

### 1.1. Need for the study

Complaint about difficulty to understand speech in noisy situations and tinnitus, was reported by young musicians despite normal hearing found through traditional audiological testing (Seever, Johnson, Baldwin, Danhauer, Wolfe, & Jeannont (2018). Emmerich, Rudel, and Richter (2008) conducted a study on classical orchestra musicians and found significant decrease in OAE amplitudes which correlated with the increase in duration of exposure being professional musicians. Gholamreza, Mehrdad, and Pourhosein (2016) concluded in their study that long-term exposure to loud sounds puts musicians at risk of hearing loss which was studied through pure tone audiometry. It is known that cochlear compression decreases with the increased severity of cochlear lesions; therefore the DPOAE slope can represent a variable with high specificity and low sensitivity. The DPOAE slope is the growth rate of the DPOAE responses, and the slope value decreases at higher stimulus intensities, especially in the range from 50 to 80 dB pe SPL, where the cochlear compression occurs. Therefore, it is a valuable measure of cochlear functioning (Campos et al, 2011). Thus, the above studies suggest that there could be a subtle cochlear impairment in instrumental musicians. There are no studies which have attempted to explore differences in cochlear non-linearity, if any, in instrumental musicians. It is well reported that DPOAE I/O function can explore the changes in cochlear functioning. Further, the slope of DPOAE I/O function is a test of cochlear non-linearity which unexplored in instrumental musicians. There is dearth of literature in finding out cochlear physiology using DPOAE input output function in instrumental musicians. Further, which type of musical instrument has higher risk of damage on cochlea needs to be studied. The DPAOE I/O function might provide an earlier detection of damage than the conventional audiological tests. Thus, the present study attempts to investigate DPOAE I/O function (in terms of slope and area) between individuals without formal training and instrumental musicians. This study also attempted to study these differences, if any across different frequencies. Hence, the study would help in exploring and understanding of cochlear physiology in instrumental musicians.

## 1.2. Aim of the study

To find the DPOAE I/O function in instrumental musicians for various test frequencies.

## 1.3. Objectives

1. To compare the slope of input/output function of DPOAEs in individuals with and without formal musical training.
2. To compare the area under DPOAE I/O in individuals with formal musical training and without formal musical training.
3. To study the effect of frequency on DPOAE I/O slope and area of DP I/O in individuals with formal musical training and without formal musical training.
4. To compare the slope of DPOAE input/output (DP I/O) and area under DP I/O among subcategory of instrumental musicians.

## 1.4. Null Hypotheses

1. There is no significant difference in the slope of input/output function of DPOAEs in individuals with and without formal musical training.
2. There is no significant difference in the area under DPOAE I/O in individuals with formal musical training and without formal musical training.

3. There is no significant difference in the effect of frequency on DPOAE I/O slope and area of DP I/O in individuals with formal musical training and without formal musical training.
4. There is no significant difference in the slope of DPOAE input/output (DP I/O) and area under DP I/O among subcategory of instrumental musicians.

# Chapter 2

# Review of Literature

Music is a form of art and it plays an important role in human culture. Sense of hearing is very important, as it provides crucial information during musical activity in order to play proficiently. The effect of music training on the auditory system is discussed below.

## 2.1. Effect of musical training in musicians

**2.1.1. Positive effects of musical training on auditory system.** It has generally been accepted that musicians have better hearing acuity and musical perception for their age than non-musicians and or amateur musicians (Schon, Magne, & Besson2004; Kazkayasi, Yetiser, & Ozeelik, 2006). Musical training would help an individual to better perceive the attributes of pitch, loudness, timbre (Marozeau, Innes-Brown, & Blamey, 2013). Bidelman, Schug, Jennings, and Bhagat, (2014) studied forward and simultaneous masked psychophysical tuning curves and their results showed sharper tuning curves in musicians than non musicians. Thus, suggesting that their pervasive auditory benefits may be facilitated by physiological mechanisms as early as the cochlea. Study by Micheyl, Khalfa, Perrot, and Collet (1997) showed that there was greater amplitude reduction in evoked otoacoustic emissions upon contralateral noise stimulation in musicians compared to non musicians which indicated greater MOCB activity in musicians than in non musicians. An abundance of research evidence suggests that musicians over perform non-musicians on a variety of tasks, ranging from basic psycho acoustical skills to speech perception in noise (Barry, Weiss, & Sabisch, 2013; Parbery-Clark, Skoe, Lam, & Kraus, 2009). Musicians are shown to perform superiorly than non musicians on a variety of other non auditory skills such as information processing speed, intelligence, memory (Tierney & Kraus, 2013), problem-solving tasks (Lovett & Anderson, 1994), higher-level cognitive functions (Schellenberg, 2006). Individuals who had undergone formal training in music appears to have enhancement in processing not only in music, but also linguistic and non-linguistic cognitive processing (Schellenberg, 2004; Hannon & Trainor, 2007). Musical training has shown to improve cognitive abilities like digit span (Fujioka, Ross, Kakigi, Pantev, & Trainor, 2006), and reading complex words (Moreno et al., 2009).

**2.1.2. Negative effects of musical training on auditory system.** The importance of hearing acuity cannot be overstated. Unfortunately, the levels of exposure during practice, rehearsal and performance are capable of damaging the hearing mechanism. Musicians are especially vulnerable to the effects of high noise level due to their continual exposure in practice and performance (Early & Horstman, 1996). Though their exposure is intermittent, musicians are still at risk for suffering from the devastating effects of NIHL, because of the sound levels produced by instruments.

Long-term exposure to loud sounds puts musicians at risk of hearing loss (Gholamreza et al, 2016). Professional pop/rock/jazz musicians' exposure to amplified music had higher hearing thresholds in the frequency range of 3-6 kHz and reported symptom of tinnitus (Halevi-Katz, Yaakobi, & Putter-Katz, 2015). In the study by Kazkayasi et al (2006), although their results indicated musical training had positive effects in terms of hearing acuity and musical perception using conventional audiometric measurements, they also found hearing reduction in extended high frequencies of 12, 14, and 16 kHz after two years of musical training and practice.

The decrease in average hearing acuity at these frequencies might be attributed to continuous noise exposure.

There is ongoing debate regarding a correlation between high sound levels and hearing disorders. The most commonly assumed causes of hearing disorders that affect musicians are the high sound levels to which they are exposed (Hart, Geltman, Schupbach, & Santucci, 1987). These hearing disorders can manifest themselves in several ways, and can represent a great burden for those affected. From the previous studies done on classical musicians, five different hearing disorders were assumed to be caused by high sound levels resulting music. They are: hearing loss, tinnitus, hyperacusis, distortion, diplacusis (Kahari, Axelsson, Hellstorm, & Zachau, 2001).

However, controversies are reported justifying the fact that music is more intermittent and varying having less detrimental effect on hearing acuity. Thus, few studies report that music is more pleasant and does not exhibit oto-traumatic effect on musicians. On the other hand there are various studies which report musicians are at risk to develop music induced hearing loss due to continual exposure to loved music.

### 2.2. DPOAE input output function

Otoacoustic emissions (OAE) provide an index of cochlear function and are linked to outer hair cell health (Kemp, 2002). The sound induced vibrations by the OHCs in the cochlea which are by-products of compressive non-linear amplification, which enhances both the frequency resolution of hearing and sensitivity are referred to as DPOAEs (Robles, Ruggero, 2001; Moore, 2007). DPOAEs are dependent on presentation level of the tones, and an input/output (I/O) function that can be obtained by keeping the stimulus frequency and frequency ratio constant. The input-output function slope obtained for different input levels is directly reliant on cochlear health and therefore gives a picture of the supra-threshold nonlinear characteristics of the cochlea. The level-dependent growth of the DPOAE as depicted by an input/output (I/O) function provides a way for indirect metric of cochlear compressive nonlinearity and is similar in gross form to that measured directly from the basilar membrane of laboratory animals, most notably at the peak of the traveling wave (Ruggero et al, 1997). It is also similar to compression inferred from human perceptual data (Boege, Janssen 2001).

Input/output functions of Distortion product otoacoustic emission is characterized by steep growth at low stimulus levels and amplitude saturation at moderate-to-high levels (Abdala, 2000). A truncated I/O function is shown by hearing-impaired ears, because of increase in the DPOAE threshold, an extended region of monotonic growth, and slightly steeper slope of DPOAE growth beyond the compression threshold (Dorn et al, 2001).

Features measured from DPOAE I/O function have shown to correlate with perceptual measures of compression such as temporal masking curves and categorical loudness scaling (Williams & Bacon, 2005), suggesting they can provide objective measures of perceptual phenomena. In impaired ears, the slope of the I/O function was steeper (Dorn et al 2001). Weighted extrapolation I/O functions of DPOAE can be used as a valuable clinical tool for the objective assessment of cochlear hearing loss as there is high correlation and relatively small differences between objectively estimated DPOAE threshold and subjectively determined hearing threshold of pure-tone audiograms (Oswald & Janssen 2003). DPOAE I/O function is a valuable measure of cochlear functioning (Campos et al, 2011).

Studies in the past have been conducted to study various auditory and non auditory skills in musicians. Studies in musicians have been done using conventional tests such as pure tone audiometry, tympanometry, reflexometry, otoacoustic emissions, auditory evoked potentials etc. There could be subtle changes in cochlea which may be unidentified by the above tests. The DPOAE input-output function slope and area obtained for different input levels, is directly reliant on cochlear health and therefore gives a picture of the supra-threshold nonlinear characteristics of the cochlea. However, there is dearth of literature regarding effect of musical training on cochlear physiology using DPOAE I/O function which is unexplored in instrumental musicians. Henceforth, the study was taken up with the aim to find out DPOAE I/O function in instrumental musicians.

# Chapter 3

# Methods

The present study aimed at measuring DPOAE I/O function in individuals with formal musical training and without musical training. In order to investigate this, the following method was used.

## 3.1. Selection of participants

Sixty participants who are in age range of 18 to 35 years were recruited for the study. The experimental group consisted of 40 musical instrumental musicians with minimum of five years of experience. Further, experimental group was divided into four categories based on the instrument played i) percussion, ii) string, iii) membranophones and iv) wind instruments. The control group consisted of 20 participants in the age range of 18 to 35 years having no formal musical training. All participants were required to fill a consent form before testing, which specified their willingness to take part in the study.

### 3.1.1. Inclusion criteria

- Musicians were defined as those involved in practicing or performing music with an instrument (piano, keyboard, drum, violin, guitar, mandlin, viola, tabala, mrudangam, flute, saxophone, double bass, & ghata) for minimum of five years.
- Musicians with degree of music – BA (M), MA (M) or musical proficiency with junior/senior completed or western instruments-minimum of grade II completion.
- Hearing sensitivity within normal limits in both ears.
- Presence of DPOAEs above 6 dB in at least three frequencies.

### 3.1.2. Exclusion criteria

Individuals who presented with any of the following were not considered for the study:

- having history or presence of middle ear disorders
- any neurological dysfunction
- any psychological dysfunction
- any other conditions like tinnitus
- if they were smokers or alcoholics
- if they were under any medications for other ailments
- if they were using any type of ear protective devices
- if they report to be using earphones for more than 2 hours/day on a daily basis.

## 3.2. Test environment

All the participants were subjected to tests in an acoustically treated room which met the ambient noise level criteria specified by ANSI S3.1-1999 (R2008).

## 3.3. Procedure

All subjects underwent a questionnaire interview followed by otoscopy, pure-tone audiometry, immittance, OAE's, DPOAE I/O function measurements. To avoid effects of TTS all the evaluations were done after providing a hearing rest (> 8 hours without music exposure).

**3.3.1. Preliminary evaluations.** The following preliminary evaluations were carried out in this study.

**Case history**. As a first step, a detailed case history was taken and a questionnaire was administered on all the participants to rule out any pathological conditions of auditory system and to procure information about their working environment and work experience. Questionnaire for musicians (Rajalakshmi, 2011) was used in this study (given in Appendix 1). This questionnaire included the following five domains: Basic information, musical history, medical history, life style, and self-assessment of hearing status. Information sought from musical history included queries on musical training and musical proficiency, regarding their musical performance/concerts and on music teaching sessions and exposure to music during teaching hours.

**Otoscopy.** It was performed on all the participants wherein the ears were examined to check for the presence of ear wax, and to assess the eardrum status. Those with excessive cerumen and or abnormalities of ear canal and/or eardrum were referred to otolaryngologist for medical management.

**Pure-tone audiometry.** Audiometric thresholds were measured using Grason Stadler Incorporation, Model 61 (GSI 61) audiometer. Air conduction thresholds were measured for octave frequencies from 250 Hz to 8000 Hz. Bone conduction thresholds were obtained for frequencies from 250 Hz to 4000 Hz using a Radio Ear B-71 bone vibrator. The audiometric thresholds were obtained using modified Hughson and Westlake procedure given by Carhart & Jerger, in 1959, in a sound treated room. To rule out 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. The mean age and age range of the individuals considered for the study is provided in table 3.1.

**Speech audiometry.** Speech audiometry was carried wherein speech recognition threshold (SRT) and speech identification scores (SIS) were obtained.

Kannada paired-word list developed at the department of Audiology, AIISH, Mysore was used to obtain Speech Recognition Thresholds (SRT). Phonemically Balanced Kannada Word Test (Yathiraj & Vijayalakshmi, 2005) was used to obtain Speech Identification Scores (SIS).

**Immittance audiometry.** Tympanometry and acoustic reflex testing was carried out to rule out the presence any middle ear dysfunction. Immittance evaluation included tympanometry and acoustic reflex testing using 226 Hz probe tone at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz using GSI-Tympstar middle ear analyzer.

**3.3.2. OAE measurements**. Cochlear functioning was checked using a calibrated Otodynamics ILO V6 Echoport system. DPOAEs were obtained for two tones, f1 and f2 (primaries), their ratio (f2/f1) being 1.22, with intensities of 65 dB SPL and 55 dB SPL (L1 and L2) respectively. A + 6 dB SNR at three consecutive frequencies were accepted as presence of OAEs. Participants satisfying the above mentioned selection criteria were included for further evaluations.

**Input/ output function of DPOAE**. I/O function of DPOAEs was measured in a sound treated room using calibrated Otodynamics ILO V6 Echoport system. Test was carried out for tones of frequencies 1000 Hz, 1500 Hz, 2000 Hz, 3000 Hz, 4000 Hz, and 6000 Hz with ratio of f2/f1 at 1.22, for different intensities. Intensities were set as primary tone stimulus is L1 = (0.4 x L2) +39 dB SPL, as the L2 decreases in 5 dB steps according to the stimulus paradigm found to be optimal for clinical testing (Kummer, Janssen, Hulin, & Arnold, 2000). With the above mentioned parameters, test was carried out. The procedure consisted of two phases, where the first phase included a check fit done to obtain correct fit by giving a transient stimulus (frequency sweep) and checking the waveform and spectrum. The second phase was measurement of DPOAE amplitude at different intensity for each frequency. The emissions at each level were plotted automatically by the instrument. An average of three responses was taken for each response. The slope of Input/Output function of DPOAE was calculated using the linear trend model. The Input/Output of DPOAE data was fitted with linear functions for the stimulus range from 65 to 35 dB SPL. Once linear fit was obtained, the slope was estimated at 2 points of the x coordinate equal with x2 = 65 dB SPL and x1 = 35 dB SPL. Given the corresponding points of DPOAE amplitude as y2 and y1, the slope of the fitted linear function was defined as b = (y2–y1) / (x2–x1) (Campos, Hatzopoulos, Kochanek, Sliwa, Skarzynski, & Carvallo, 2011).

The area under the curve was determined using the difference between the noise floor and DP amplitude at all the 5 dB stimulus step levels from 65 dB SPL to 35 dB SPL. Responses are considered valuable only if the amplitude of DPOAE are above the noise floor and further analysis was done. Gates , Mills, Nam, D'Agostino and Rubel (2002) proposed the procedure to find the area under the curve by calculating the cumulative amplitude of the DP responses above the noise floor at each if the intensity levels and multiplying it by 5 which is reported in $dBSPL^2$ ($area^2$). The square root of $area^2$ was used for the analysis.

Table 3.1

*Mean pure tone average, mean age and age range of subjects participated in the study*

| | Number of subjects | Age ( in years) | | | |
|---|---|---|---|---|---|
| Subcategory | | Mean | Standard Deviation | Range | Mean PTA (dB) |
| Control group | 20 | 23.3000 | 1.83819 | 18-35 | 6.05 |
| Percussion | 10 | 24.9000 | 6.08185 | 18-35 | 7.5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | instruments | | | | | |
| Clinical group | String instruments | 10 | 21.7000 | 2.49666 | 18-35 | 7.0 |
| | Membranophones | 10 | 21.4000 | 2.11870 | 18-35 | 7.5 |
| | Wind instruments | 10 | 20.0000 | 1.82574 | 18-35 | 7.5 |

### 3.4. Statistical Analysis

Shapiro-Wilks test for normality was done, and the data was not normally distributed ($p < 0.05$), hence non parametric tests were chosen for analysis. Descriptive statistics for determining median, minimum and maximum were done for both area and slope measurements of DPOAE I/O function at various test frequencies in individuals with and without formal musical training. Mann-Whitney U test was done to compare the slope and area between individuals with and without formal musical training. A non-parametric Kruskal-wallis test was done to see the significant difference across groups of instrumental musicians. Further, Mann-Whitney test was done to see the pair wise significant difference between types of instrumental users. A non-parametric Friedmans test was done to see significant difference across frequencies in area and slope.

# Chapter 4

# Results

The study compared DPOAEs in two groups, a control group of individuals without formal musical training and an experimental group of instrumental users with formal musical training and further subcategorized as percussion, string, membranophones and wind instrumental users respectively. The control group had 20 participants and experimental had a total of 40 participants. Slopes and Areas of DPOAE input output function for six frequencies were compared between the two groups. All the data obtained was analyzed using statistical package of social science (SPSS) software version 21.0. The Shapiro Wilk's test of normality was administered to check whether the raw data is normally distributed or not and was found to be not normally distributed ($p < 0.05$). Hence, the non-parametric tests were chosen for further analysis. The following statistical tests were carried out:

- Descriptive statistics was done to find median, minimum and maximum for both slope and area measurements of DPOAE I/O function at various test frequencies in individuals with and without formal musical training.
- Mann-Whitney U test was done to compare the slope and area between individuals with and without formal musical training.
- Friedman's test to see effect of frequencies on slope and area of DPOAE function in individuals with and without formal musical training and Wilcoxon Signed rank test for pair wise comparison across frequencies.
- Kruskal-Wallis test was done to see significant difference across groups of instrumental musicians. Since there was significant difference found at 4000 Hz in slope, Mann-Whitney U test was done for pair wise comparison among subcategory of instrumental musicians.

The results of the study are explained under following headings:

4.1 Comparison of slope of input/output function of DPOAEs in individuals with and without formal musical training at various test frequencies.

4.2 Comparison of area of input/output function of DPOAEs in individuals with and without formal musical training at various test frequencies.

4.3 Effect of frequency on slope of DPOAE I/O and area under DPOAE I/O in individuals with formal musical training and without formal musical training separately.

4.4 Comparison of slope of DPOAE input/output function and area under DPOAE input/output function among subcategory of instrumental musicians.

**4.1 Comparison of Slope of input/output function of DPOAEs in individuals with and without formal musical training at various test frequencies**

Descriptive statistics was carried out to find the median, minimum of slope of input/ output function of DPOAE's in individuals with and without formal musical training at various test frequencies. This is represented in Table 4.1. The data showed that the individuals with formal musical training had higher median score at all test frequencies (1500 Hz, 2000 Hz, 3000 Hz, 4000 Hz, & 6000 Hz) except 1000 Hz than the individuals without formal musical training.

Table 4.1

*Median, Minimum and Maximum values of the slopes of DPOAE I/O function in individuals with and without formal musical training*

| | | Slope | | | | | |
|---|---|---|---|---|---|---|---|
| Groups | Statistics | 1kHz | 1.5kHz | 2kHz | 3kHz | 4kHz | 6kHz |
| | Median | .5480 | .6860 | .8100 | .8315 | .8080 | .9040 |
| Non-musicians | Min | .05 | .15 | .06 | .12 | .02 | .18 |
| | Max | .99 | .99 | .99 | 1.00 | 1.00 | .99 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Musicians | Median | .5045 | .7655 | .9155 | .9155 | .9140 | .9460 |
| | Min | .01 | .02 | .00 | .05 | .21 | .20 |
| | Max | 1.00 | .99 | .99 | 1.00 | 1.00 | 1.00 |

The values for slope (Table 4.2) for individuals with and without formal musical training were compared between the two groups using Mann-Whitney U test. Significant difference ($p < 0.05$) were noticed between the two groups at 3000 Hz, 4000 Hz, and 6000 Hz. There was no significant difference ($p > 0.05$) between the two groups for slope at 1000 Hz, 1500 Hz, and 2000 Hz.

Table 4.2

*Mann-Whitney test U test results for slopes of DPOAE I/O function in individuals with and without formal musical training across various test frequencies.*

| Frequency | U | \|Z\| | p value |
|---|---|---|---|
| 1 kHz | 1569.000 | 0.173 | .863 |
| 1.5 kHz | 1371.000 | 1.275 | .202 |
| 2 kHz | 1316.500 | 1.578 | .114 |
| 3 kHz | 1240.000 | 2.004 | .045 |
| 4 kHz | 1085.500 | 2.864 | .004 |
| 6 kHz | 1246.000 | 1.971 | .049 |

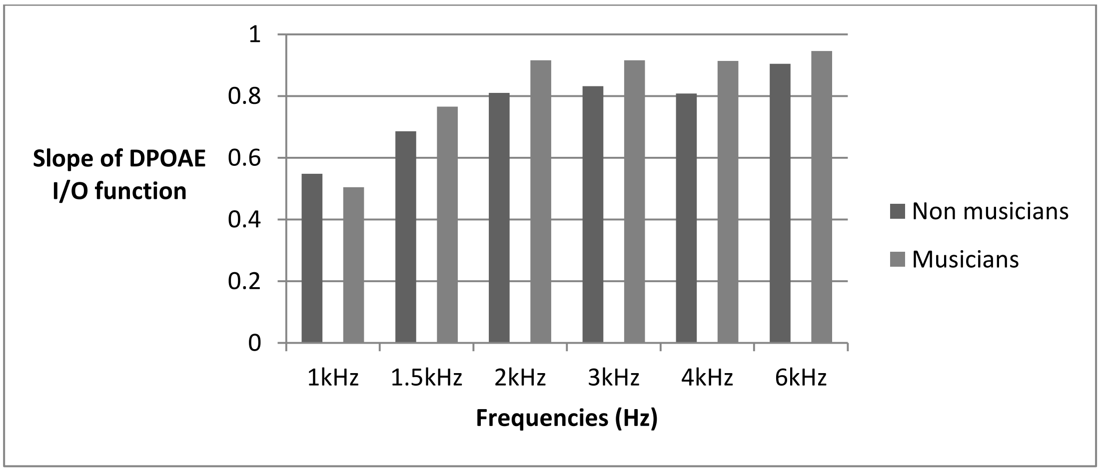


*Figure 4.1* Comparison of median slope between individuals with and without musical training.

**4.2 Comparison of Area of input/output function of DPOAEs in individuals with and without formal musical training at various test frequencies**

Descriptive statistics was carried out to find the median, minimum, maximum of area of input/ output function of DPOAE's in individuals with and without formal musical training at various test frequencies. This is represented in Table 4.3. The data showed that the individuals with formal musical training had higher median score at all test frequencies 1000 Hz, 1500 Hz, 2000 Hz, 3000 Hz, 4000 Hz, & 6000 Hz) than the individuals without formal musical training.

Table 4.3

*Median, minimum, maximum of the areas of DPOAE I/O function in individuals with and without formal musical training*

| | | Area | | | | | |
|---|---|---|---|---|---|---|---|
| Groups | Statistics | 1 kHz | 1.5kHz | 2 kHz | 3 kHz | 4 kHz | 6 kHz |
| Non-Musicians | Median | .54800 | .68600 | .81000 | .83150 | .80800 | .9040 |
| | Min | 2.44 | .00 | .00 | 1.73 | 2.36 | 3.39 |
| | Max | 24.91 | 24.83 | 24.59 | 24.12 | 26.22 | 28.21 |
| Musicians | Median | .50450 | .76550 | .91550 | .91550 | .91400 | .9460 |
| | Min | 4.24 | 1.58 | 1.58 | 4.30 | 4.90 | 5.20 |
| | Max | 27.33 | 28.09 | 28.20 | 28.78 | 32.04 | 32.28 |

The values for area (Table 4.4) for individuals with and without formal musical training were compared between the two groups using Mann-Whitney U test. Significant difference ($p < 0.05$) was noticed between the two groups at all test frequencies (1000 Hz, 1500 Hz, 2000 Hz, 3000 Hz, 4000 Hz, & 6000 Hz).

Table 4.4

*Mann-Whitney test U test results for areas of DPOAE I/O function in individuals with and without formal musical training across various test frequencies.*

| Frequencies | U | \|Z\| | p value |
|---|---|---|---|
| 1 kHz | 1037.000 | 3.134 | .002 |
| 1.5 kHz | 895.000 | 3.925 | .000 |
| 2 kHz | 863.000 | 4.103 | .000 |
| 3 kHz | 501.500 | 6.116 | .000 |
| 4 kHz | 617.000 | 5.473 | .000 |
| 6 kHz | 959.000 | 3.569 | .000 |

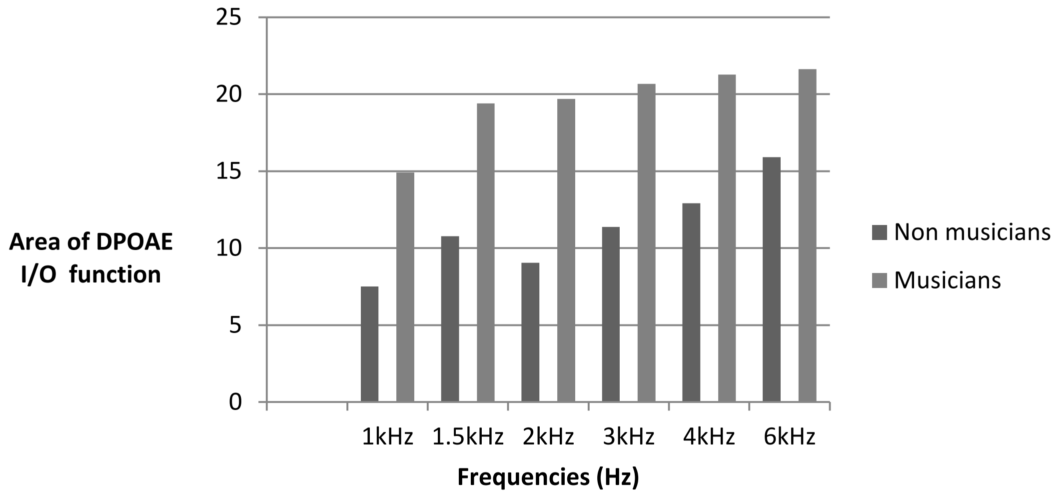


*Figure 4.2* Comparison of median slope between individuals with and without musical training.

### 4.3 The effect of frequency on slope of DPOAE input output function and area under DPOAE input output function in individuals with formal musical training and without formal musical training

Friedmans test was done to compare slope and area across frequencies in individuals with and without formal musical training separately. The results of Friedmans test are shown in the Table 4.5 for both the groups.

Table 4.5

*Test statistics for Friedman's test for slope and area of DPOAE I/O function in individuals with formal musical training and without formal musical training*

| | Musicians | | Non-Musicians | |
|---|---|---|---|---|
| Statistics | Slope | Area | Slope | Area |
| Chi-square | 19.943 | 89.223 | 26.461 | 49.686 |
| Significance | .001 | .000 | .000 | .000 |

The results showed that there was a significant difference across all test frequencies ($p < 0.05$) for both slope and area of DPOAE I/O function in individuals with formal musical training and without formal musical training.

The Table 4.6 shows results of Wilcoxon signed rank test for slope of DPOAE I/O function in individuals without formal musical training. The results revealed significant difference for 2 kHz – 1 kHz, 3 kHz – 1 kHz, 4 kHz – 1 kHz, 6 kHz – 1 kHz and 6 kHz – 1.5 kHz.

Table 4.6

*Test statistics for Wilcoxon signed rank test for slope of DPOAE I/O function in individuals without formal musical training*

| | \|Z\| | Significance |
|---|---|---|
| 1.5 kHz – 1 kHz | 1.210 | .226 |
| 2 kHz – 1 kHz | 2.366 | .018* |
| 3 kHz – 1 kHz | 3.085 | .002* |
| 4 kHz – 1 kHz | 2.164 | .030* |
| 6 kHz – 1 kHz | 3.643 | .000* |
| 2 kHz – 1.5 kHz | 1.707 | .088 |
| 3 kHz – 1.5 kHz | .625 | .532 |
| 4 kHz – 1.5 kHz | 1.129 | .259 |
| 6 kHz – 1.5 kHz | 2.722 | .006* |
| 3 kHz – 2 kHz | .105 | .917 |
| 4 kHz – 2 kHz | .269 | .788 |
| 6 kHz –2 kHz | 1.371 | .170 |
| 4 kHz – 3 kHz | .440 | .660 |
| 6 kHz – 3 kHz | 1.297 | .195 |
| 6 kHz – 4 kHz | 1.848 | .065 |

*significant difference ($p < 0.05$)

The Table 4.7 shows results of Wilcoxon signed rank test for area of DPOAE I/O function in individuals without formal musical training. The results revealed significant difference for 4 kHz – 1 kHz, 6 kHz – 1 kHz, 4 kHz – 1.5kHz, 6 kHz – 1.5 kHz, 6 kHz – 2 kHz, 4 kHz – 3 kHz, 6 kHz – 3 kHz and 6 kHz – 4 kHz.

Table 4.7

*Test statistics for Wilcoxon signed rank test for area of DPOAE I/O function in individuals without formal musical training*

| | \|Z\| | Significance |
|---|---|---|
| 1.5 kHz – 1 kHz | 1.358 | .175 |
| 2 kHz – 1 kHz | 1.116 | .265 |
| 3 kHz – 1 kHz | 1.237 | .216 |

| | | |
|---|---|---|
| 4 kHz –1 kHz | 2.245 | .025* |
| 6 kHz – 1 kHz | 3.415 | .001* |
| 2 kHz – 1.5kHz | .780 | .436 |
| 3 kHz –1.5kHz | .215 | .830 |
| 4 kHz – 1.5kHz | 2.030 | .042* |
| 6 kHz – 1.5kHz | .845 | .000* |
| 3 kHz – 2 kHz | .148 | .882 |
| 4 kHz – 2 kHz | 1.922 | .055 |
| 6 kHz – 2 kHz | 3.939 | .000* |
| 4 kHz – 3 kHz | 2.379 | .017* |
| 6 kHz – 3 kHz | 3.657 | .000* |
| 6 kHz – 4 kHz | 2.310 | .021* |

*significant difference ($p < 0.05$)

Table 4.8 shows results of Wilcoxon signed rank test for slope of DPOAE I/O function in individuals with formal musical training. The results revealed significant difference for 1.5 kHz – 1 kHz, 2 kHz – 1 kHz, 3 kHz – 1 kHz, 4 kHz – 1 kHz, 6 kHz – 1 kHz, 3 kHz – 1.5 kHz, 4 kHz – 1.5 kHz and 6 kHz – 1.5 kHz and 6 kHz – 2 kHz.

Table 4.8

*Test statistics for Wilcoxon signed rank test for slope of DPOAE I/O function in individuals with formal musical training*

| | \|Z\| | Significance |
|---|---|---|
| 1.5 kHz – 1 kHz | 3.676 | .000* |
| 2 kHz – 1 kHz | 5.119 | .000* |
| 3 kHz – 1 kHz | 6.033 | .000* |
| 4 kHz –1 kHz | 6.180 | .000* |
| 6 kHz – 1 kHz | 6.523 | .000* |
| 2 kHz – 1.5kHz | 1.856 | .063 |
| 3 kHz –1.5kHz | 3.427 | .001* |
| 4 kHz – 1.5kHz | 2.849 | .004* |
| 6 kHz – 1.5kHz | 4.758 | .000* |
| 3 kHz – 2 kHz | 1.285 | .199 |
| 4 kHz – 2 kHz | 1.345 | .179 |
| 6 kHz – 2 kHz | 2.558 | .011* |
| 4 kHz – 3 kHz | .279 | .780 |
| 6 kHz – 3 kHz | 1.851 | .064 |
| 6 kHz – 4 kHz | 1.718 | .086 |

*significant difference ($p < 0.05$)

The Table 4.9 shows results of Wilcoxon signed rank test for area of DPOAE I/O function in individuals with formal musical training. The results revealed significant difference for 1.5 kHz – 1 kHz, 2 kHz – 1 kHz, 3 kHz – 1 kHz, 4 kHz – 1 kHz, 6 kHz – 1 kHz, 3 kHz – 1.5 kHz, 4 kHz – 1.5 kHz, 6 kHz – 1.5 kHz,  6 kHz – 1.5 kHz, 4 kHz – 2 kHz, and 6 kHz – 2 kHz.

Table 4.9
*Test statistics for Wilcoxon signed rank test for area of DPOAE I/O function in individuals with formal musical training*

| | \|Z\| | Significance |
|---|---|---|
| 1.5 kHz – 1 kHz | 4.115 | .000* |
| 2 kHz – 1 kHz | 3.775 | .000* |
| 3 kHz – 1 kHz | 5.583 | .000* |
| 4 kHz –1 kHz | 5.976 | .000* |
| 6 kHz – 1 kHz | 4.940 | .000* |
| 2 kHz – 1.5kHz | .648 | .517 |
| 3 kHz –1.5kHz | 2.590 | .010* |
| 4 kHz – 1.5kHz | 3.468 | .001* |
| 6 kHz – 1.5kHz | 3.029 | .002* |
| 3 kHz – 2 kHz | 1.741 | .082 |
| 4 kHz – 2 kHz | 2.967 | .003* |
| 6 kHz – 2 kHz | 2.170 | .030* |
| 4 kHz – 3 kHz | 1.861 | .063 |
| 6 kHz – 3 kHz | .859 | .391 |
| 6 kHz – 4 kHz | .667 | .505 |

*significant difference ($p < 0.05$)

Thus, it can be seen that there was significant difference for slope and area in individuals with and without formal musical training when 1000 Hz was paired with other test frequencies and when 1500 Hz was paired with other test frequencies.

**4.3.1 The effect of frequency on slope of DPOAE input output function and area under DPOAE input output function in percussion users.** Friedmans test was done to compare slope and area across frequencies in percussion users. The results are depicted in Table 4.10.

Table 4.10

*Test statistics for Friedman's test for slope and area of DPOAE I/O function in percussion instrument users*

| | slope | area |
|---|---|---|
| Chi-Square | 16.314 | 10.571 |
| Significance | .006 | .061 |

The results showed that there was a significant difference across all test frequencies ($p < 0.05$) for slope and there was no significant difference found across all test frequencies ($p > 0.05$) for area of DPOAE I/O function.

Table 4.11 shows results of Wilcoxon signed rank test for slope of DPOAE I/O function in percussion instrument users. The results revealed significant difference for 1.5 kHz – 1 kHz, 2 kHz – 1 kHz, 3 kHz – 1 kHz, 4 kHz – 1 kHz, and 6 kHz – 1 kHz.

Table 4.11

*Test statistics for Wilcoxon signed rank test for slope of DPOAE I/O function in percussion instrument users*

| | \|Z\| | Significance |
|---|---|---|
| 1.5 kHz – 1 kHz | 2.184 | .029* |
| 2 kHz – 1 kHz | 2.875 | .004* |
| 3 kHz – 1 kHz | 2.912 | .004* |
| 4 kHz – 1 kHz | 2.539 | .011* |
| 6 kHz – 1 kHz | 2.912 | .004* |
| 2 kHz – 1.5 kHz | .784 | .433 |
| 3 kHz – 1.5 kHz | .933 | .351 |
| 4 kHz – 1.5 kHz | .187 | .852 |
| 6 kHz – 1.5 kHz | 1.60 | .108 |
| 3 kHz – 2 kHz | .710 | .478 |
| 4 kHz – 2 kHz | .504 | .614 |
| 6 kHz – 2 kHz | .691 | .490 |
| 4 kHz – 3 kHz | .597 | .550 |
| 6 kHz – 3 kHz | .056 | .955 |
| 6 kHz – 4 kHz | .989 | .322 |

*significant difference ($p <0.05$)

Thus, it can be seen that there was a significant difference for slope of DPOAE I/O function in percussion instrument users when 1000 Hz was paired with other test frequencies.

**4.3.2 The effect of frequency on slope of DPOAE input output function and area under DPOAE input output function in string instrument users.** Friedmans test was done to compare slope and area across frequencies in string users. The results are depicted in Table 4.12.

Table 4.12

*Test statistics for Friedman's test for slope and area of DPOAE I/O function in string instrument users*

| | slope | area |
|---|---|---|
| Chi-Square | 28.764 | 22.686 |
| Significance | .000 | .000 |

The results showed that there was a significant difference across all test frequencies ($p < 0.05$) for both slope and area of DPOAE I/O function in string users.

The Table 4.13 shows results of Wilcoxon signed rank test for slope of DPOAE I/O function in string instrument users. The results revealed significant difference for 1.5 kHz – 1 kHz, 2 kHz – 1 kHz, 3 kHz – 1 kHz, 4 kHz – 1 kHz, 6 kHz – 1 kHz, 3 kHz – 1.5 kHz, 4 kHz – 1.5 kHz, 6 kHz – 1.5 kHz, 4 kHz – 2 kHz and 6 kHz – 2 kHz.

Table 4.13

*Test statistics for Wilcoxon signed rank test for slope of DPOAE I/O function in string instrument users*

| | \|Z\| | Significance |
|---|---|---|
| 1.5 kHz – 1 kHz | 2.165 | .030* |
| 2 kHz – 1 kHz | 1.979 | .048* |
| 3 kHz – 1 kHz | 3.501 | .000* |
| 4 kHz – 1 kHz | 3.696 | .000* |
| 6 kHz –1kHz | 3.771 | .000* |

| | | |
|---|---|---|
| 2 kHz – 1.5 kHz | .224 | .823 |
| 3 kHz – 1.5 kHz | 2.016 | .044* |
| 4 kHz – 1.5 kHz | 2.576 | .010* |
| 6 kHz – 1.5 kHz | 2.987 | .003* |
| 3 kHz – 2 kHz | 1.811 | .070 |
| 4 kHz – 2 kHz | 2.315 | .021* |
| 6 kHz – 2 kHz | 2.072 | .038* |
| 4 kHz – 3 kHz | .893 | .372 |
| 6 kHz – 3 kHz | .971 | .332 |
| 6 kHz – 4 kHz | .161 | .872 |

*significant difference (p <0.05)

Table 4.14 shows results of Wilcoxon signed rank test for area of DPOAE I/O function in string users. The results revealed significant difference for 3 kHz – 1 kHz, 4 kHz – 1 kHz, 6 kHz – 1 kHz, 3 kHz – 1.5 kHz, 4 kHz – 1.5 kHz, 6 kHz – 1.5 kHz and 4 kHz – 2 kHz .

Table 4.14
*Test statistics for Wilcoxon signed rank test for area of DPOAE I/O function in string instrument users*

| | \|Z\| | Significance |
|---|---|---|
| 1.5 kHz – 1 kHz | 1.381 | .167 |
| 2 kHz – 1 kHz | 1.904 | .057 |
| 3 kHz – 1 kHz | 2.091 | .037* |
| 4 kHz – 1 kHz | 2.949 | .003* |
| 6 kHz – 1 kHz | 3.061 | .002* |
| 2 kHz – 1.5 kHz | 1.531 | .126 |
| 3 kHz – 1.5 kHz | 2.016 | .044* |
| 4 kHz – 1.5 kHz | 2.389 | .017* |
| 6 kHz – 1.5 kHz | 2.688 | .007* |
| 3 kHz – 2 kHz | 1.195 | .232 |
| 4kHz – 2kHz | 2.091 | .037* |
| 6kHz – 2kHz | 1.437 | .151 |
| 4kHz – 3kHz | 1.456 | .145 |
| 6kHz – 3kHz | .373 | .709 |
| 6kHz – 4kHz | 635 | .526 |

*significant difference (p <0.05)

Thus, it can be seen that there was significant difference for slope and area in string users when 1000 Hz was paired with other test frequencies and when 1500 Hz was paired with other test frequencies.

### 4.3.3 The effect of frequency on slope of DPOAE input output function and area under DPOAE input output function in membranophone instrument users.

Friedmans test was done to compare slope and area across frequencies in membranophone instrument users. The results are depicted in Table 4.15.

Table 4.15
*Test statistics for Friedman's test for slope and area of DPOAE I/O function in membranophone instrument users*

| | slope | area |
|---|---|---|
| Chi-Square | 32.934 | 17.686 |
| Significance | .000 | .003 |

The results showed that there was a significant difference across all test frequencies ($p < 0.05$) for both slope and area of DPOAE I/O function in membranophone instrument users.

Table 4.16 shows results of Wilcoxon signed rank test for slope of DPOAE I/O function in membranophone instrument users. The results revealed significant difference for 2 kHz – 1 kHz, 3 kHz – 1 kHz, 4 kHz – 1 kHz, 6 kHz – 1 kHz, 2 kHz – 1.5 kHz, 3 kHz – 1.5 kHz, 4 kHz – 1.5 kHz, 6 kHz – 1.5 kHz.

Table 4.16
*Test statistics for Wilcoxon signed rank test for slope of DPOAE I/O function in membranophone instrument users*

| | \|Z\| | Significance |
|---|---|---|
| 1.5kHz – 1kHz | 1.195 | .232 |
| 2kHz – 1kHz | 3.421 | .001* |
| 3kHz – 1kHz | 3.061 | .002* |
| 4kHz – 1kHz | 3.696 | .000* |
| 6kHz – 1kHz | 3.360 | .001* |
| 2kHz – 1.5kHz | 2.240 | .025* |
| 3kHz – 1.5kHz | 2.147 | .032* |
| 4kHz – 1.5kHz | 2.576 | .010* |
| 6kHz – 1.5kHz | 2.053 | .040* |
| 3kHz – 2kHz | 1.381 | .167 |
| 4kHz – 2kHz | .709 | .478 |
| 6kHz – 2kHz | .000 | 1.000 |

| | | |
|---|---|---|
| 4kHz – 3kHz | 1.960 | .050 |
| 6kHz – 3kHz | .896 | .370 |
| 6kHz – 4kHz | 1.344 | .179 |

*significant difference ($p < 0.05$)

Table 4.17 shows results of Wilcoxon signed rank test for slope of DPOAE I/O function in membranophone instrument users. The results revealed significant difference for 3 kHz – 1 kHz, 4 kHz – 1 kHz, 6 kHz – 1 kHz, 3 kHz – 1.5 kHz, 4 kHz – 1.5 kHz, 6 kHz – 1.5 kHz and 4 kHz – 2 kHz.

Table 4.17
*Test statistics for Wilcoxon signed rank test for area of DPOAE I/O function in membranophone instrument users*

| | \|Z\| | Significance |
|---|---|---|
| 1.5kHz – 1kHz | 1.381 | .167 |
| 2kHz – 1kHz | 1.904 | .057 |
| 3kHz – 1kHz | 2.091 | .037* |
| 4kHz – 1kHz | 2.949 | .003* |
| 6kHz – 1kHz | 3.061 | .002* |
| 2kHz – 1.5kHz | 1.531 | .126 |
| 3kHz – 1.5kHz | 2.016 | .044* |
| 4kHz – 1.5kHz | 2.389 | .017* |
| 6kHz – 1.5kHz | 2.688 | .007* |
| 3kHz – 2kHz | 1.195 | .232 |
| 4kHz – 2kHz | 2.091 | .037* |
| 6kHz – 2kHz | 1.437 | .151 |
| 4kHz – 3kHz | 1.456 | .145 |
| 6kHz – 3kHz | .373 | .709 |
| 6kHz – 4kHz | .635 | .526 |

*significant difference ($p < 0.05$)

Thus, it can be seen that there was significant difference for slope and area in membranophone users when 1000 Hz was paired with other test frequencies and when 1500 Hz was paired with other test frequencies.

**4.3.4 The effect of frequency on slope of DPOAE input output function and area under DPOAE input output function in wind instrument users.** Friedmans test was done to compare slope and area across frequencies in wind instrument users. The results are depicted in Table 4.18.

Table 4.18
*Test statistics for Friedman's test for slope and area of DPOAE I/O function in wind instrument users*

| | slope | area |
|---|---|---|
| Chi-Square | 25.086 | 21.314 |
| Significance | .000 | .001 |

The results showed that there was a significant difference across all test frequencies ($p < 0.05$) for both slope and area of DPOAE I/O function in string users.

Table 4.19 shows results of Wilcoxon signed rank test for slope of DPOAE I/O function in wind instrument users. The results revealed significant difference for 2 kHz – 1 kHz, 3 kHz – 1 kHz, 4 kHz – 1 kHz, 6 kHz – 1 kHz, 6 kHz – 1.5 kHz and 6kHz – 4 kHz.

Table 4.19

*Test statistics for Wilcoxon signed rank test for slope of DPOAE I/O function in wind instrument users*

| | \|Z\| | Significance |
|---|---|---|
| 1.5kHz – 1kHz | 1.792 | .073 |
| 2kHz – 1kHz | 2.165 | .030* |
| 3kHz – 1kHz | 2.651 | .008* |
| 4kHz – 1kHz | 2.464 | .014* |
| 6kHz – 1kHz | 3.248 | .001* |
| 2kHz – 1.5kHz | 1.269 | .204 |
| 3kHz – 1.5kHz | 1.605 | .108 |
| 4kHz – 1.5kHz | .411 | .681 |
| 6kHz – 1.5kHz | 2.800 | .005* |
| 3kHz – 2kHz | 1.045 | .296 |
| 4kHz – 2kHz | .075 | .940 |
| 6kHz – 2kHz | 2.203 | .028 |
| 4kHz – 3kHz | 1.475 | .140 |
| 6kHz – 3kHz | 1.904 | .057 |
| 6kHz – 4kHz | 2.670 | .008* |

*significant difference ($p < 0.05$)

The Table 4.20 shows results of Wilcoxon signed rank test for area of DPOAE I/O function in wind instrument users. The results revealed significant difference for 1.5 kHz – 1 kHz, 2 kHz – 1 kHz, 3 kHz – 1 kHz, 4 kHz – 1 kHz, 6 kHz – 1 kHz, and 3 kHz – 1.5 kHz .

Table 4.20

*Test statistics for Wilcoxon signed rank test for area of DPOAE I/O function in wind instrument users*

| | \|Z\| | Significance |
|---|---|---|
| 1.5 kHz – 1 kHz | 2.278 | .023* |
| 2 kHz – 1 kHz | 2.726 | .006* |
| 3 kHz – 1 kHz | 3.099 | .002* |
| 4 kHz – 1kHz | 3.585 | .000* |
| 6 kHz – 1 kHz | 3.211 | .001* |
| 2 kHz – 1.5 kHz | 1.606 | .108 |
| 3 kHz – 1.5 kHz | 2.054 | .040* |
| 4 kHz – 1.5 kHz | 1.531 | .126 |
| 6 kHz – 1.5 kHz | 1.942 | .052 |
| 3 kHz – 2 kHz | .187 | .852 |
| 4 kHz – 2 kHz | .597 | .550 |
| 6 kHz – 2 kHz | .261 | .794 |
| 4 kHz – 3 kHz | .485 | .627 |
| 6 kHz – 3 kHz | .560 | .575 |
| 6 kHz – 4 kHz | 1.270 | .204 |

*significant difference ($p < 0.05$)

Thus, it can be seen that there was significant difference for slope and area in membranophone users when 1000 Hz was paired with other test frequencies and when 1500 Hz was paired with other test frequencies.

Thus, the results under this section showed that the effect of frequency on slope and area of DPOAE input output function was significant in both the groups. Further, pair wise comparison showed that there was significant difference in slope and area when 1000 Hz and 1500 Hz were paired with all other test frequencies in both the groups. The same trend was observed among subcategory of instrumental users.

### 4.4 Comparison of slope of DPOAE input/output and area under DP I/O among subcategory of instrumental users

Kruskal-wallis test was done to see significant difference across groups of instrumental users. The results showed that there is significant difference ($p < 0.05$) between the two groups for slope of DPOAE I/O function at only 4000 Hz among subcategory of instrumental users. There was no significant difference ($p > 0.05$) found for area under DPOAE I/O function among subcategory of instrumental users. Further, Mann-Whitney U test was performed at 4000 Hz to see pair wise significant difference among subcategory of instrumental users.

The results showed that there was no significant difference ($p > 0.05$) found between percussion and wind instrumental users, percussion and membranophone instrumental users, percussion and string instrumental users, string and membranophone instrumental users. There was significant difference ($p < 0.05$) found between string and wind instrumental users, membranophones and wind instrumental users respectively. The results of Kruskal-Wallis test are shown in Table 4.21. The results of Mann-Whitney U test are shown in Table 4.22.

Table 4.21

*Test statistics for Kruskal-wallis test for slope and area of DPOAE I/O function among subcategory of instrumental musicians*

| | Chi-Square | Significance |
|---|---|---|
| 1kHz | 1.619 | .655 |
| 1.5kHz | 2.023 | .568 |
| 2kHz | 5.970 | .113 |
| 3kHz | 1.376 | .711 |
| 4kHz | 8.535 | .036* |
| 6kHz | 4.025 | .259 |
| 1kHz | .704 | .872 |
| 1.5kHz | 4.568 | .206 |
| 2kHz | 5.492 | .139 |
| 3kHz | .740 | .864 |
| 4kHz | 2.188 | .534 |

| | | |
|---|---|---|
| 6kHz | .585 | .900 |

*significant difference

Table 4.22

*Test statistics Z values for Mann-Whitney U test for pair wise comparison of slope at 4000Hz among subcategory of instrumental users*

| | Mann-Whitney U | \|Z\| | Significance |
|---|---|---|---|
| Percussion- Wind | 181.000 | 0.514 | .607 |
| Percussion- Membranophones | 128.500 | 1.935 | .053 |
| Percussion- String | 132.500 | 1.827 | .068 |
| Membranophones- String | 197.500 | 0.68 | .946 |
| Membranophones- wind | 116.000 | 2.273 | .023* |
| String - Wind | 122.500 | 2.097 | .036* |

**significant difference*

Overall, the test results revealed significant difference in slope and area of DPOAE I/O function in individuals with and without musical training. Hence, the first and second null hypothesis was rejected. Further, as the effect of frequency on slope and area of DPOAE input output function was significant in individuals with and without musical training, the third null hypothesis is rejected. There was no significant difference found in slope and area of DPOAE I/O function among subcategory of instrumental users except 4000 Hz. Hence, the forth null hypothesis is accepted.

# Chapter 5

# Discussion

The aim of the present study was to find DPOAE input output function in instrumental musicians. In this study, comparison of slope and area of DPOAE I/O function in individuals with and without formal musical training, effect of frequency on slope and area in individuals with and without formal musical training, comparison of slope and area of DPOAE input output function among subcategory of instrumental users were done. The results obtained in the study are discussed below.

The noise produced while playing musical instruments during practice and performance has deleterious effect on auditory system. Study by Jansen, Helleman, Dreschler, and de Laat (2009) reported a 6000 Hz notch in pure tone audiograms of 241 professional symphony orchestra musicians which is a frequency associated with noise induced hearing loss and had complaints of tinnitus and hyperacusis. Krishnamurti (2012) studied hearing status in musicians using audiometry and DPOAES. Their results reported no significant difference in hearing thresholds but a significant difference in amplitudes of DPOAE. Thus, indicating DPOAE as a valuable tool in monitoring of acoustic overexposure in musicians. Emmerich et al (2008) assessed hearing status in classical orchestral musicians (109) using pure tone audiometry and OAE tests. Their results reported that more than 50% of the musicians were found to have permanent hearing shift of 15 dB or more and found significant decline in OAE amplitudes which correlated with the length of time being professional musicians.

## 5.1 Comparison of slope of DPOAE input output function in individuals with and without formal musical training

The results showed that the slope of DPOAE input output function in individuals with formal musical training was found to be steeper at higher frequencies compared to individuals without formal musical training. The increased steepness of the slope indicates a relatively better functioning of the cochlea in individuals with musical abilities. The enhanced perception of music may induce changes in the cochlea which assists in better appreciation of music. Previous studies on musicians have also showed improved performance in auditory and cognitive skills such as auditory attention, auditory stream segregation, processing of prosody and linguistic feature (Tierney & Kraus, 2013). Studies have also shown that musicians have improved speech perception in the presence of noise (Jain, Mohamed, & Kumar, 2015) and better fine structure abilities (Mishra, Panda, & Raj, 2015). Musical training would help an individual to better perceive the attributes of pitch, loudness, timbre (Marozeau, Innes-Brown, & Blamey, 2013). Thus, musical training has positive effect on cochlear functioning. Thus, the current finding is in consensus with the previously reported studies.

## 5.2. Comparison of area of DPOAE input output function in individuals with and without formal musical training

The results showed that the area in individuals with formal training was more at all test frequencies than the individuals without formal musical training, which also indicates that the DPOAE amplitude was more in instrumental users. Study by Micheyl et al (1997) showed that there was greater amplitude reduction in evoked otoacoustic emissions upon contralateral noise stimulation in musicians compared to non-musicians which indicated greater MOCB activity in musicians than in non-musicians. Bidelman et al (2014) studied forward and simultaneous masked psychophysical tuning curves and their results showed sharper tuning curves in musicians than non-musicians. Thus, suggesting that the music exposure has benefits shown at the cochlear level. Bidelman, Schneider, Heitzmann, and Bhagat, (2017) measured efferent feedback through otoacoustic emissions. The results indicated that the ipsilateral and contralateral cochlear efferent control was enhanced in trained musicians. MOC strength was correlated with years of listener's training, suggesting that efferent gain control is experience dependent. This study provided evidence that intensive listening experience (s) (e.g., musicianship) can strengthen the ipsi/contralateral MOC efferent system and sound regulation to the inner ear. The current study showed increased area under DPOAE input output function which indicates enhanced cochlear functioning which is correlating with the previous studies.

### 5.3. DPOAE I/O function in instrumental users and the effect of frequency

The results showed that there was significant difference of slope at 4000 Hz only among subcategory of instrumental users. Further, pair wise comparison revealed significant difference when wind instrumental users were paired with string and membranophone instrument users. This could be because of frequency characteristics of the instruments. This shows that there is better cochlear tuning at 4000 Hz. Study by Bidelman et al  (2014) found more selective tuning at 4000 Hz compared to other characteristic frequencies in musicians. Thus, we can say that there is not much difference in cochlear functioning across subgroups of instrumental users. Irrespective of the instruments played, all lead enhancement of cochlear function. The results showed that the effect of frequency on slope and area of DPOAE input output function was significant in both the groups. Further, pair wise comparison showed that there was significant difference in slope and area when 1000 Hz and 1500 Hz were paired with all other test frequencies in both the groups. Bride, Gill, Proops, Harrington, Gardiner, and Attwell (1992) assessed 89 classical orchestral musicians by comparing the hearing levels between woodwind and brass musicians (high risk group) with 18 string musician (low risk group) matched for age and gender. It was found that there was no significant difference in hearing thresholds between high risk group and low risk group. Minnesota Orchestra members (42 males, 18 females) aged 24 to 64 years, all asymptomatic for hearing problems or ear disease, were evaluated with a hearing history questionnaire, otolaryngologic examination, and pure tone audiometry for the conventional (0.25 to 8 kHz) and extended high frequency (9 to 20 kHz) ranges. Hearing sensitivity was examined with respect to musician instrument type, years of playing, and orchestral stage position. Type of instrument played and position on the orchestral stage had no significant correlation with hearing loss (Johnson, Sherman, Aldridge, & Lorraine 1985). The results of this study indicates that there is an increase in the slope of DPOAE I/O function as the f2 frequency increases from 1 kHz to 2 kHz which is in agreement with the previous studies done by Abdala (2000), and Probst, Lonsbury-Martin, Martin (1993) where the results shows a similar trend of increase in the slope with the frequency. The increase in the f2 frequency resulted in increase in the area in all the conditions tested. This could be attributed to the increase in DPOAE amplitude with the frequency which is leading to the overall improvement in the area. The increase in the levels of DPOAE amplitudes across the frequencies in normal hearing individuals has described previously in the literature (Dorn, Piskorski, Keefe, Neely, & Gorga, 1998). A similar trend was observed in instrumental users wherein with increase in frequency, slope (except at 4000 Hz) and area of DPOAE I/O function increased.

Thus, it can be seen that there is significant difference in cochlear physiology in individuals with formal musical training and without formal musical training which is evidenced through significant difference in slope and area of DPOAE I/O function in both the groups. There is dearth of literatures in DPOAE I/O function in instrumental users. The current study is one of the first studies to explore DPOAE I/O function in instrumental users.

# Chapter 6

## Summary and Conclusions

Music plays a crucial role in professional musicians. They are exposed to loud music for more hours since they involve in practicing and performing musical programs and concerts. Most of the musicians are unaware that, their exposure to loud music can put them at a high a risk of music induced hearing loss. Emmerich et al (2008) reported that at exposure to such loud levels of music, hearing loss has been shown to occur in a higher proportion of professional musicians. The prevalence of music induced hearing loss in musicians varies between studies depending upon study design and how hearing loss is defined. Studies have reported overall prevalence of hearing loss among student musicians (N = 329) aged 18 – 25 years was 45% and with 78% of notches occurring at 6000 Hz. The proportion of the total population with bilateral notching at any frequency was 11.5%, mostly occurring at 6000 Hz (Phillips, Henrich, & Mace, 2010). Even though the pure tone audiogram shows normal hearing thresholds, there could be subtle cochlear changes DPOAE test is reliant on cochlear health. DPOAE I/O function can give good picture of cochlear non-linearity. Henceforth, the study was taken up with the aim of finding DPOAE I/O function in instrumental users. The study included 20 individuals without formal musical training and 40 individuals with formal musical training for at least five years. Further, instrumental musicians included subcategories of percussion instrument users (10), string instrument users (10), membranophone instrument users (10) and wind instrument users (10).

Slope and area of DPOAE I/O was assessed in both the groups and effect of frequency on the same was assessed. The results revealed significant difference in slope and area of DPOAE I/O function in individuals with and without musical training. The effect of frequency on slope and area of DPOAE input output function was significant in individuals with and without musical training. There was no significant difference found in slope and area of DPOAE I/O function among subcategory of instrumental users except 4000 Hz. The slope and area of DPOAE I/O function was found to be more in instrumental users.

Thus, it can be concluded that music can either have positive and/ or negative effect. The current study revealed positive effect of music on cochlear function in individuals with formal musical training. DPOAE I/O function as a tool to identify cochlear damage in instrumental users is questionable.

## 6.1 Implications of the study

1. DPOAE I/O function can be used as an additional tool in test battery assessment of hearing in instrumental musicians as it give picture about cochlear non-linearity.

2. The findings of the study can be used in counseling student musicians and professional musicians regarding effect of musical training on hearing in a positive way; along with guiding with using ear protective measures such as ear protective devices.

## 6.2 Future directions

1. Longitudinal studies can be done to investigate the relationship between music exposure and NIHL in order to clarify possible risks and important factors.

2. To investigate the correlation between duration of exposure and DPOAE I/O function.

3. To investigate correlation between younger and older musicians DPOAE I/O function.

## 6.3 Limitations of the study

1. DPOAE I/O function was not carried out in specific group of instrumental users in large number to get a clear picture of cochlear physiology for generalization.

2. Extended high frequency thresholds were not assessed.

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## Appendix 1

## QUESTIONNAIRE FOR MUSICIANS (Rajalakshmi, 2011)

**I. Basic information**

Name: Age:
Gender:
Occupation: DOB:
Education:

**II. Musical history:**

A) Musical training and proficiency:

1. Are you trained in some form of formal musical training? Vocal/ Instrumental
   If instrumental, which instrument?
2. Onset (age) of musical training:
3. Since how long (no of yes) have been practicing music?
4. How often do you practice music (no of hours/week):
5. Musical proficiency:
6. Do you have any professional qualifications in music? Yes/No
   If yes, please describe:

B) Musical performances/concerts:

1. Do you give performances/concerts? Yes/ No
2. If yes, how often do you perform?
   Once in a week/once in 15days/ once in a month/ once in 3 months/ once in 6 months.
3. If along with accompanists, who are your usual accompaniments?

C) Musicians who are involved in teaching:

1. Do you teach music? Yes/No
2. If yes, which form of music? Vocal/Instrumental
3. If instrumental, which instrument?
4. Total number of students you teach?
5. Do you teach in groups/ one to one?
6. If in groups, do you teach students in different batches? Yes/No
7. If yes, how many students in a batch?
8. No of hours spent on teaching in a day?
9. No of days spent teaching in a week?
10. Total number of hours spent on teaching in a week?

**III. Medical history**

Hearing health:

1. Do you have hearing loss/ difficulty? Ears: Right/left/Both
2. If yes, age of onset of hearing difficulty.
3. Nature of hearing difficulty. Progressive/ fluctuating
4. Specify difficult to listen situations if any?
5. H/O ear discharge/ ear pain/ ear infections: Yes/ No

6. H/O ear surgery: Yes/ No
7. Do you have buzzing/ ringing sensation in either ear? Yes/ No
8. Do you have any difficulty tolerating sounds? Yes/ No
9. H/O dizziness/ vertigo: Yes/No
10. Does anyone have H/O hearing loss in your family?
11. Have you undergone any hearing evaluation in the past?
12. Do you indulge in any other music exposure? Yes/ No
13. Do you work in a noisy environment? Yes/ No
14. If yes, since how many years have you been working there?
15. Do you wear any ear protective devices? (ear muff/ ear plugs)
16. Do you indulge in any noisy leisure time activities?
17. Were you exposed to any impulse noise? (Cracker burst etc.)
18. When you were last exposed to noise/ music?
19. Do you take special care about your voice and vocal hygiene?

**IV. Self-assessment of hearing status**

1. Do you hear people speaking, but have difficulty understanding the words?
2. Do you notice you are favouring one ear than the other?
3. Do you find yourself asking others to repeat themselves?
4. Do people seem to mumble often, making it hard for you to understand that?
5. Do you problems in understanding certain women voice?
6. Do you have difficulty following conversation in noisy background?
7. At what volume do you hear music or TV program? Low/ moderate/ high/ very high
8. Do you have any problem in understanding or conversing over telephone?
9. If you attend other musical programs, where do you prefer to sit?
10. Do you have any other concerns to share?