DOES PROLONGED EXPOSURE TO MUSIC INCREASE LISTENING EFFORT AND FATIGUE?

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CERTIFICATE

This is to certify that this dissertation titled '**Does prolonged exposure to music increase listening effort and fatigue?'** is the Bonafede work submitted as part fulfilment for the Degree of Master of Science in Audiology of the student with Registration No: P01II21S0073 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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DECLARATION

This dissertation titled ‘**Does prolonged exposure to music increase listening effort and fatigue?’** is the result of my own study under the guidance of, Ms. Indira C. P. Asst. Professor of Audiology Department of Audiology, All India Institute of Speech and Hearing, and has not been submitted earlier to any other University for the award of any other diploma or degree.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Background: Hearing loss due to excessive exposure to loud music is a common phenomenon which is termed as music induced hearing loss. Exposure to high levels of music causes effects similar to that of exposure to the high levels of noise including hearing loss and difficulty in understanding speech in noise. However, the effect of prolonged exposure to high levels of music, on listening effort and listening related fatigue are not well studied.

Aim: The study aimed to understand listening effort and fatigue in individuals exposed to music for a prolonged period of time.

Method: 45 individuals in the age range of 18 to 35 years, took part in the study. They were divided into music listners and non-music listners based on their duration of exposure to music through personal listening devices. After collecting demographic data, output sound pressure levels were measured from the personal listening devices (in the music listeners). Listening effort was measured using dual task paradigm, and listening related fatigue was measured using Vanderbilt fatigue scale adult-40 questionnaire in Kannada.

Results: The findings showed a significant difference in listening-related fatigue between music listners and non-music listners.

Conclusion: listening related fatigue was significantly higher among long term listners of music. Since this was seen in the absence of hearing loss or other symptoms, auditory fatigue may be used as an early tool to detect the effects of prolonged exposure to loud music.

Chapter I

INTRODUCTION

Recreational noise, including loud music is a prominent threat to hearing health. The World Health Organization's (WHO) campaign report ahead of the world hearing day 2022 mentioned that over 1 billion individuals in the age range of 12 to 35 years are at risk of hearing loss due to excessive exposure to recreational sounds (WHO, 2022). Hearing loss and its effects are particularly common with excessive exposure to loud music, that hearing loss acquired due to this is termed 'Music induced hearing loss.'

Use of personal listening devices is highly prevalent, that on an average 82% of teenagers listen to music approximately for two and half hours every day (Rideout & Robb, 2019). The recommended safe levels of exposure to music through such devices is 'not more than 4 hours per day while the volume is at 70% or for 90 minutes when volume is at 80%' (Berg et al., 2016). Unsafe listening habits, however, are very common among teenagers and young adults. Approximately 23.81% of them listen to music at levels above what is recommended to be safe (Dillard et al., 2022).

According to a WHO estimate, 1.1 billion people (or 50% of the world's population) are at danger of hearing damage as a result of using personal listening devices and being around music that is louder than 120 dB (WHO, 2015). Excessive exposure to loud music can lead to symptoms like hearing loss, tinnitus, sound distortions, hyperacusis, and diplacusis (Kujawa & Liberman, 2009). However, even before the clinical symptoms appear, music listeners obtain significantly higher scores on the noise exposure questionnaire (Bernard et al., 2019), and people exposed to loud music for more than 2 years complain of tinnitus. Music exposure has also been reported as a reason for synaptopathy (Kujawa & Liberman, 2009).

Prefrontal and auditory cortices are said to differ in their plasticity in response to noise exposure (Wieczerzak et al., 2020). Cognitive skills like attention and working memory are affected in individuals exposed to noise (Irgens-Hansen et al., 2015).

Increased "listening effort" may result from auditory perceptual deficits, even in the absence of quantifiable hearing loss, because different cognitive resources are allocated to understanding different messages. This is very evidently seen in individuals exposed to noise ((World Health Organization, 2021; Lopez-Poveda, 2014; Bramhall et al., 2019)). People who have a history of listening to loud noises for extended periods of time may experience listening-related fatigue as a result of this. That is, due to a distinct allocation of cognitive resources for listening, deficiencies in various cognitive areas combined with auditory perceptual deficits might lead to an increase in listening effort and subsequent fatigue (Bess & Hornsby, 2014).

As long-term exposure to unsafe levels of music may have consequences comparable to those of exposure to noise, listening effort and listening fatigue may be increased in those who have experienced this.

1.1 Need for the Study

By increasing awareness, establishing policies, and employing methods, hearing loss caused by prolonged exposure to loud music can be prevented. According to reports, recreational music exposure at higher levels has effects on the listener that are comparable to those of noise exposure. Long-term exposure to noise may result in increased listening effort. Similarly, persons with long-term exposure to loud music may also experience increased listening effort. There is evidence that extended exposure to loud music can adversely affect hearing (Kujawa & Liberman, 2009). But, since increased listening effort and fatigue may occur as pre-clinical symptoms, studying these parameters in music listeners is necessary. Considering that increasing proportion of the population has access to personal listening devices which can expose them to high levels of music, an exploration of the impact of prolonged exposure to high levels of music through personal listening devices is warranted.

1.2 Aim of the study

Aim of the proposed study is to investigate whether listening to high levels of music over an extended period of time will lead to increased listening effort and fatigue.

1.3 Objectives

1. To compare listening effort between individuals with and without prolonged exposure to high levels of music using the dual task paradigm.
2. To compare listening related fatigue between individuals with and without prolonged exposure to high levels of music, using VFS-A-40 questionnaire.
3. To compare the DPOAE amplitude levels between individuals with and without prolonged exposure to high levels of music.

1.4 Null Hypotheses

2. There is no significant effect of music exposure on listening effort.
3. There is no significant effect of music exposure on listening related fatigue.
4. There is no significant effect of prolonged exposure to high levels of music on the DPOAE amplitude.

Chapter II

REVIEW OF LITERATURE

The literature review will discuss the concepts and studies related to hidden hearing loss, music-induced hearing loss, and listening effort and listening-related fatigue

2.1 Hidden Hearing Loss

Hidden hearing loss refers to a condition where an individual experiences difficulty in understanding speech in the presence of noise in the absence of any quantifiable hearing loss on standard audiological tests like pure-tone audiometry (World Health Organization, 2021; Lopez-Poveda, 2014; Bramhall et al., 2019). The symptoms may typically be linked to exposure to loud noise. It is reported to be highly prevalent, where approximately one out of every ten patients who seek help at a hearing clinic mentions that they continue to experience unresolved speech-in-noise challenges because the root cause of their hearing issues cannot be pinpointed (Pryce and Wainwright, 2008; Tremblay et al., 2015; Parthasarathy et al., 2020).

Hidden hearing loss is reported to significantly impact an individual on their overall quality of life. Individuals with hidden hearing loss have to exert extra effort during everyday conversations. In the absence of any discernible hearing loss, audiologists are not equipped to precisely diagnose hidden hearing loss, let alone treat it .(Mealings, K., Yeend, 2020)There is no consistent, evidence-based protocol to diagnose and address patients with this condition.

Four different neurophysiological mechanisms are proposed to be the underlying causes of hidden hearing loss – cochlear synaptopathy, auditory nerve demyelination, elevated central gain, and neural mal-adaptation. They affect the ability of an individual to process sounds even if hearing thresholds remain unaffected.

2.1.1 Cochlear Synaptopathy

The concept of cochlear synaptopathy was first proposed by. Kujawa and Liberman in 2009 observed that mice exposed to an octave band noise for a duration of 2 hours at a sound pressure level of 100 dB experienced a sudden and permanent reduction in the specialized synaptic ribbons located within the cochlear sensory hair cells. These synaptic ribbons play a crucial role in releasing neurotransmitters that activate the neural transmission along the auditory nerve. Damage to the synapses were seen to cause deterioration in the auditory nerve fibres. Sensory hair cells themselves were observed to be undamaged in the study.

The findings by Kujawa and Liberman (2009) were confirmed by studies conducted by Lin et al. (2011), Furman et al. (2013), Bing et al. (2015), Niwa et al. (2016), Chambers et al. (2016), Maison et al. (2016), Bourien et al. (2014), Gleich et al. (2016), and Valero et al. (2017). The observation has been validated in guinea pigs, rats, mice, gerbils, and rhesus monkeys. The findings indicate that auditory nerve fibers with higher thresholds for sound-induced activity are more vulnerable to the adverse effects of loud sounds, particularly noise exposure. In contrast, nerve fibers with lower thresholds are comparatively less impacted by these effects.

Cochlear synaptopathy is also considered to be the primary mechanism underlying neural degeneration in age-related hearing loss (Sergeyenko et al. (2013) and Kujawa and Liberman (2015)). The premise set is that both the natural aging process and exposure to loud noises directly influence the neural processing of sounds above the typical hearing thresholds. Therefore, it is suggested that cochlear synaptopathy significantly contributes to the challenges in understanding speech in noisy environments, even in the presence of normal audiograms.

2.1.2 Auditory Nerve Demyelination

Another possible cause of hidden hearing loss is demyelination of the auditory nerve. Wan and Corfas (2017) recorded ABRs and DPOAEs from mice exposed to noise at

100 dB SPL for 2 hours a day for 16 weeks. They also did histopathological analysis of the noise exposed tissue. They observed changes in ABR wave I, and reported that loss of cochlear Schwann cells in the peripheral terminals of Type I and an inability to repair the same by the nervous system may be a potential cause of hidden hearing loss. Auditory nerve demyelination could occur even in the absence of exposure to noise and even compound the impacts of cochlear synaptopathy.

Demyelination can diminish the neural synchrony within the auditory nerve, and this can reflect in the morphology of the auditory brainstem responses. Wan and Corfas (2017) reported a decrease in the amplitude and an increase in the latency of ABR wave I as an indicator of auditory nerve demyelination. They also reported an increased latency between the first and second waves of the ABR due to a longer neural transmission time from the cochlea to the cochlear nucleus. If the cause of hidden hearing loss is auditory nerve demyelination, it could potentially affect the temporal precision of auditory processing (Stange-Marten et al. (2017). This, in turn, could lead to difficulties in understanding speech in noisy environments.

2.1.3 Elevated Central Gain

The third possible cause for hidden hearing loss is elevated central gain, which is an enhanced neural sensitivity or activity within the central auditory system. It is a homeostatic mechanism, and enhancement can be seen even at the level of the cochlear nucleus (Schaette and Kempter in 2006). It may also be seen at the level of inferior colliculus in the midbrain (Schaette and McAlpine (2011), Auerbach et al. (2014), Hesse et al. (2016), and Monaghan et al. (2020),) and in the auditory cortex (Resnik and Polley in 2021).

Hesse et al. (2016) studied how young adult male mice responded to exposure to two distinct noise levels, specifically 100 dB SPL and 105 dB SPL. They used a variety of techniques, including multiunit recordings from the Inferior Colliculus, ABR measures, and cochlear immune-histochemistry (a technique to analyse inner ear tissues). An octave-band noise with a frequency range of 8–16 kHz was used to deliver the noise exposure, and it lasted for two hours. The mice were given general anaesthesia before being exposed. The findings indicated that the elevation in central gain was more noticeable in animals with synaptopathy (exposed to 100 dB SPL noise) than in those with a permanent increase in their hearing threshold (exposed to 105 dB SPL noise). The findings indicate a non-linear relationship between subtle cochlear damage and elevated central gain.

2.1.4 Neural mal-adaptation

The fourth proposed reason for hidden hearing loss is neural mal-adaptation, which is described as a situation where neurons within the auditory pathway are unable to adjust their response to loud acoustic environments in a way that optimizes the encoding of information within those environments. This concept, which may be crucial for comprehending speech in noisy settings, was introduced by Dean et al. in 2005. Dean et al. (2008) demonstrated in guinea pigs that neurons in the auditory midbrain adapt their firing patterns based on the average sound level in the background. This adaptive process results in improved sensitivity to those specific sound levels over time.

This type of neural adaptation was also observed auditory nerve fibers (Wen et al. in 2009), and the auditory cortex (Watkins and Barbour in 2008). Bakay et al. (2018) discovered that the capacity of midbrain neurons to adapt to loud sound environments was compromised in mice with noise-induced synaptopathy compared to control mice with no prior noise exposure. This finding suggests that difficulties in hearing speech in noisy environments in humans may result from inadequate neural adaptation to loud sound environments.

Exposure to high levels of noise may cause hidden hearing loss in human beings. The symptoms observed could be attributed to synaptopathy, auditory nerve demyelination, elevated central gain, neural maladaptation, or a combination of the factors. Nevertheless, exposure to loud sounds for long could result in auditory perceptual difficulties.

2.2 Music Induced Hearing Loss

Recreational noise can also lead to hearing loss and other auditory perceptual difficulties. Prolonged exposure to music at volumes exceeding 85 decibels through headphones or listening devices can result in music-induced hearing loss, with college students, particularly males, being susceptible due to exceeding recommended listening levels and lacking awareness of safe thresholds (Dillard et al., 2022). Excessive exposure to loud music can lead to symptoms like hearing loss, tinnitus, sound distortions, hyperacusis, and diplacusis (Kujawa & Liberman, 2009).

According to the World Health Organization (WHO) and its ‘2021 World Report on Hearing’ it is estimated that half of the world's population is at risk of developing hearing loss due to unsafe listening practices. These practices encompass exposure to loud sounds both in occupational settings and recreational activities. The safe listening practices for high levels of sounds through personal listening devices (PLDs) are for 2 hours at 70% of device volume and for 90 minutes at 80% of the device volume (Berg et al., 2016). However, college students increase the volume above safe levels in order to avoid environmental sounds, and are therefore at risk for music-induced hearing loss (Berg et al., 2016). Use of personal listening devices are highly prevalent, that on an average 82% of teenagers listen to music approximately for two and half hours (Rideout & Robb, 2019), and approximately 23.81% of them listen to music above the recommended levels (Dillard et al., 2022). In fact, over 1 billion individuals in the age range of 12 to 35 years are at risk of hearing loss due to excessive exposure to recreational sounds (WHO, 2022).

Even before the clinical symptoms appear, music listeners obtain significantly higher scores on the noise exposure questionnaire (Bernard et al., 2019), and people exposed to loud music for more than 2 years complain of tinnitus. Music exposure has also been reported as a reason for synaptopathy (Kujawa & Liberman, 2009).

Exposure to higher levels of noise is reported to cause differential plasticity in the auditory and prefrontal cortices (Wieczerzak et al., 2020). The authors exposed rats to noise and recorded their spontaneous neural responses and 40 Hz auditory steady state responses. They observed enhanced event-related potentials which showed alteration in the central gain, and reduced coherence between trails in auditory steady state responses.

Irgens-Hansen et al., (2015) studied cognitive skills of 87 Navy personnel exposed to noise. The participants performed the visual attention test based on Posner cue-target paradigm, and the authors observed that the reaction time was significantly higher in individuals exposed to high levels of noises [>77 dB (A)]. The authors conclude that cognitive skills like attention and working memory are also affected in individuals exposed to noise.

Up to 1/3 of the workforce is regularly exposed to damaging levels of loud sounds (Schneider, 2005), and more than half of people aged 12–35 regularly expose themselves to sound levels that pose a risk to hearing either from personal listening devices or by attending loud venues such as nightclubs (Sliwinska-Kowalska and Zaborowski,2017).

Since the use of PLDs is highly prevalent among the public, the effects of exposure to loud recreational noise may also be expected to be highly prevalent. It is therefore important to look at early indicators of effect of exposure to loud recreational music, so as to create awareness regarding the same, and to promote safe listening practices.

2.3 Listening Effort and Listening Related Fatigue

Individuals with hearing loss have to exert more cognitive effort in order to listen effectively compared to those without hearing impairment. Each individual has limited cognitive resources, and allocating more resources to listening leaves fewer for other cognitive tasks. This cognitive load during listening is known as ‘listening effort’ is heightened in individuals with hearing loss. Consequently, individuals with hearing loss may reallocate resources from activities such as visual processing or memory rehearsal, potentially affecting their overall ease of communication (Hornsby, 2013).

The term "mental effort" refers to the conscious allocation of mental resources to overcome challenges while performing tasks, whereas "listening effort" specifically pertains to the mental effort required for tasks involving listening (Pichora-Fuller et al., 2016). "Fatigue" in the context of listening is typically assessed by a decline in physical or cognitive performance and may be associated with the tiredness resulting from sustained effortful listening (Hornsby, Naylor, & Bess, 2016; McGarrigle et al., 2014).

In contrast to individuals with normal hearing who usually don't experience this fatigue, those with hearing loss encounter it due to the brain's elevated information processing efforts aimed at compensating for the loss of auditory function. This ultimately results in cognitive strain and fatigue for individuals with hearing loss.

Effective comprehension of spoken language relies on a combination of sensory acuteness and the utilization of cognitive faculties like selective attention and working memory (Pichora-Fuller, Schneider, & Daneman, 1995). Particularly in challenging listening situations such as classrooms, there's a heightened requirement for cognitive support, leading to what's known as "effortful listening." Notably, it's believed that recurrent or prolonged instances of such effortful listening can lead to feelings of fatigue (Pichora-Fuller et al., 2016).

Listening-related effort and fatigue can manifest as changes in physiological arousal, which can be tracked through pupillometry, a technique that monitors real-time shifts in arousal and attention by measuring variations in pupil size (Beatty, 1982). Pupillometry enables continuous monitoring of arousal and attention changes during various listening tasks. Changes in pupil size correspond to fluctuations in neuronal firing patterns in the locus coeruleus (LC) of the brainstem, a region responsible for attention, alertness, and optimal task performance (Aston-Jones and Cohen, 2005; Gilzenrat et al., 2010). Given the connection between changes in physiological arousal and cognitive effort, an increase in pupil dilation from baseline is interpreted as heightened listening effort in adults (Koelewijn et al., 2014; Kuchinsky et al., 2013, 2014; Winn et al., 2015; Zekveld and Kramer, 2014). Listening effort can be measured using different tools.

Tools to measure listening effort and fatigue in children:

- Experimental Measures: Listening effort in children has been experimentally measured by examining performance decrements in listening tasks (Gustafson et al., 2014; Hicks and Tharpe, 2002; Howard et al., 2010; McCreery and Stelmachowicz, 2013). This entails observing how their task performance deteriorates as an indicator of increased effort.
- Self-Report: Self-report measures have been employed to gauge listening-related fatigue in children. This involves directly asking them about their feelings of fatigue related to listening.
- Salivary Cortisol Levels: Listening-related fatigue in children has been assessed by measuring salivary cortisol levels, which can indicate physiological responses to fatigue (Bess et al., 2016). Decreased cortisol levels have been associated with fatigue in various contexts.

Tools to measure listening related fatigue in Adults (Dwyer et al., 2019):

- Subjective Questionnaire: The Profile of Mood States (POMS) questionnaire was used to investigate subjective fatigue and vigor. Specific questions related to "listening-related" fatigue, presented through an unvalidated three-question survey, revealed significant differences between groups.
- Patient-Reported Outcome Measure (PROM): To address the gap in assessing listening-related fatigue in individuals with hearing loss, the researchers aimed to

> create a tailored Patient-Reported Outcome Measure (PROM). Focus groups were conducted to identify key domains and constructs associated with listening-related fatigue from the participants' perspectives. This guided the formulation of items for the Vanderbilt Fatigue Scale for Adults (VFS-A), a subjective tool designed to quantify listening-related fatigue.

These methods aim to capture the various facets of listening-related fatigue, which can be crucial for understanding its impact and developing effective interventions for individuals with hearing loss.

Chapter III

METHODS

3.1 Participants

A total of 45 individuals in the age range of 18 to 35 years were recruited for the study. These individuals were assigned to either 'music listeners group' or 'non-music listeners group', based on the level and duration of their exposure to music through personal listening devices. The music listeners group (n=20, mean age -22.12) consisted of individuals with exposure to music at levels above 70% of the maximum volume in their personal listening devices, for at least 14 hours a week, for over 2 years. The non-music listeners group (n=25, mean age -23.05) consisted of individuals who were exposed to music at levels lower than 70% of the maximum volume of their personal listening devices for less than 12 hours a week. None of the participants had history of exposure to other sources of hazardous levels of sounds.

All participants were native speakers of Kannada language. They could fluently speak and read Kannada and had graduate level of education. All the participants had hearing sensitivity within normal limits (4 frequency PTA <25 dB), normal middle ear functioning ('A' type tympanogram with present reflexes), and no history of otological or neurological complaints. Informed, written consent was obtained from all the participants before they took part in the study.

3.2 Procedure

3.2.1 Gathering demographic information

A custom questionnaire was used to gather the participants' demographic information (name, age, gender, qualification, phone number, language), the duration of exposure to music through personal listening devices, their otological complaints/history, and neurological complaints. The questionnaire was circulated as a Google form among

300 prospective participants. Responses were obtained from 98 individuals. The responses were scrutinized to select the participants in the music listeners group (n=20) and non-music listeners group (n=25) for further inclusion in the study.

3.2.2 Measurement of output SPL from personal listening devices

Output sound pressure levels of each participant's personal listening device in LAeq units were measured using Knowles electronic manikin for acoustic research (Kemar-model GRAS, Holte, Denmark), fitted with an ear simulator (GRAS 45BB KEMAR Head &Torso), and an A calibrated Bruel and Kjaer 2270 Sound Level Meter (SLM). Participants were instructed to set the volume level in their personal listening device in an outside environment. The earphone receiver connected to the personal listening device, with the volume set by the participant, was placed in KEMAR's ear, and one standard music was played from the device for output measurement. Output sound pressure levels, overall ear canal LAeq, and LAeq values at individual frequencies between 0.1 and 20 kHz at two points per octave were measured. Ear canal output values were converted to equivalent diffuse sound field pressure levels. LAeq values for 8-hour durations were calculated using the formula Leq8h = L T + 10 log 10 (T/8). The LAeq values varied between 89.43 and 69.12 dBA.

3.2.3 Audiological Evaluation and Measurement of Listening Effort and Fatigue

Audiological Evaluation: Audiological evaluation included otoscopic examination, pure-tone audiometry, tympanometry, and otoacoustic emission (OAE) testing. Listening effort was measured using the dual-task paradigm, and listening-related fatigue was measured using a questionnaire. A summary of the protocol used for the audiological evaluation, listening effort assessment, and measurement of listening-related fatigue is given in

Table 3.1.

- Otoscopic examination: Otoscopic examination was carried out to evaluate the structural integrity of the ear canal and tympanic membrane.

- Pure tone audiometry and immittance testing: Pure tone audiometry was carried out with the GSI AudioStar pro instrument using modified version of the Hughson-Westlake procedure (Carhart & Jerger, 1959). Air conduction (250-8000 Hz) and bone conduction (250-4000 Hz) thresholds were obtained to ensure normal hearing sensitivity of the participants. Immittance evaluation was carried out to rule out middle ear pathology. Tympanometry was performed with a standard protocol using a 226 Hz probe tone at 85 dB SPL. Ipsilateral and contralateral acoustic reflexes were obtained, measured using the same probe tone at octave frequencies from 250, 500, 1000, 2000, and 4000 Hz. Individuals with tympanometric types other than ‘A’ and its variants, or ears with absent reflexes, were excluded from the study.

- Otoacoustic emission testing: Distortion-product oto-acoustic emissions (DPOAEs) were recorded using Otodynamics ILO V6 OAE instrument with the stimulus paradigm L1/L2 = 65/55; F2:F1 ratio = 1.220. Each participant was seated comfortably in a chair and instructed to stay quiet and not move during the testing. The OAE probe was placed in the participant's ear canal, and a stable fit was ensured. DPOAEs were obtained for F2 frequencies between 842 to 9509 Hz as a measure of cochlear functioning. Testing was carried out at high frequencies, to detect subclinical damages to the auditory system manifested at high frequencies also. OAEs were obtained from both ears of the participants. Absolute amplitude and SNR of the OAEs were noted.

Measurement of Listening Effort and Fatigue: Listening effort experienced by the participants was studied using a single question as a subjective measure and using a dual-task paradigm as an objective measure. To understand the participants' perception of their speech perception abilities in the presence of noise, a single question was asked: "Do you experience difficulty understanding speech in the presence of noise?" Their responses were recorded verbatim.

Dual-task paradigm was carried out using a personal laptop computer [HP laptop 15s-dy3xxx,11th Gen Intel(R) Core (TM)] to measure listening effort. The primary task was sentence recognition, and the secondary task was last word recall of the sentences presented, in their order of occurrence. Kannada sentences from the sentence lists developed by (Geetha et al., 2014) were used for both primary and secondary tasks of dual task paradigm. The Sentences were mixed with noise using MATLAB [version R 2014a (8.3.0.532)]. Twenty-five sentences each were mixed with noise at -6dB, 0db SNR and 6dB SNRs, using a MATLAB code (Nike, 2023). The twenty-five sentences at each SNR were grouped into five blocks where each block comprised of five sentences. In a block, an interstimulus interval period was set at 2000 milliseconds and inter-block interval was provided as 2000 milliseconds. A duration of 5000 milliseconds was given to repeat the sentences for the primary task. For the recall of the last words (the secondary task) 15000 milliseconds were given. In each condition, there were five blocks (5 Sentence in each) in each SNR. The test material was presented to the participants, and responses were recorded using Psychopy software (version 2023.1.2), installed in the personal laptop. Participants were seated comfortably in a chair facing the computer monitor at a 90-degree angle. The stimuli for the primary task were delivered through calibrated Sony MDR ZX110 AP noise cancellation headphones at their MCL (Most Comfortable Loudness Level). The participants were instructed to listen carefully and understand the sentences presented to them in noise. After five sentences were presented (constituting 1 block of stimuli), they were asked to recall the last words of each of the five sentences in their order of presentation. Eight words were displayed on the test screen, and the participants were asked to enter their responses on the computer screen using a mouse.

After a familiarity run of two blocks of stimuli in quiet, the task was carried out at three different SNRs (-6, 0, and +6dB). Five blocks of sentences were presented at each SNR.

Listening related fatigue: The Vanderbilt Fatigue Scale-Adult version- 40 items (VFS-A-40) translated to Kannada [(© *2018 Vanderbilt University © 2023 Vanderbilt University (Kannada Translation , Manipal Academy of Higher Education ; Revision Date : © 2018 Vanderbilt University © 2023 Vanderbilt University (Kannada Translation , Manipal sAcademy of Higher Education ;* 2023)] was administered to assess listening related fatigue experienced by the participants. The questionnaire measured listening related fatigue by inquiring about 'how often the participant feels or responds in a specific manner in a particular circumstance' through 40 questions. The responses were obtained on a five-point rating scale (Never/Almost Never, Rarely, Sometimes, Often, almost always/Always). For example, a person who responded that they 'felt worn out from everyday listening' Almost Always/Always indicated that they were tired by the end of a day that required listening in the presence of noise. They might even avoid such situations. Conversely, if they chose "Never/Almost Never" in response to the same question, it meant that they almost never or never experienced that reaction in the described situation. The answers were scored to obtain the VFS-A total scores (ranging from 0 to 160) and subscale scores. The subscale scores were calculated (ranging from 0 to 40) under the Emotional, Social, Cognitive, and Physical subscales.

Table 3.1.

A summary of the protocol used for the audiological evaluation, listening effort assessment, and measurement of listening-related fatigue.

Test/Skill assessed	Protocol/Material	Outcome/Criteria
Pure tone audiometry	Modified version of the Hughson-Westlake procedure (Carhart & Jerger, 1959) was used to obtain air conduction (250-8000 Hz) and bone conduction (250-4000 Hz) thresholds.	Both AC and BC threshold should be within 25 dB HL
Immittance evaluation	Standard protocol used at the audiology clinic, AIISH for immittance evaluation was used to rule out middle ear pathology.	Tympanometric types A and its variants, and ears with present acoustic reflexes.
OAEs testing	DPOAEs was measured with the following stimulus paradigm: L1/L2 = 65/55; F2:F1 ratio = 1.22; F2 frequencies between 2000 Hz to 10000 Hz.	Recordings with reproducibility of 80% were considered. Absolute amplitude and SNR values was noted.
Participants' perception of their speech perception abilities in noise	The following single question was asked: "Do you experience difficulty understanding speech in the presence of noise?"	Verbatim responses were noted down.

Table 3.1 Continued…

Test/Skill assessed	Protocol/Material	Outcome/Criteria
Listening effort	Dual task paradigm Protocol: Kannada sentences from the sentence lists developed by Geetha et al. (2014) was used for primary and secondary tasks. Sentences were presented at -6, 0 and +6 dB SNRs at the participants' most comfortable level. The primary task will be sentence recognition, in the presence of noise. The participants will be instructed to understand the sentences. Secondary task (last word recall of the presented sentences) was carried out after a block of 5 sentences. The response was obtained through mouse click on a computer screen.	Any changes in the performance of the secondary task between the three different SNR conditions and between the participant groups were indicate listening effort.
Listening related fatigue	Vanderbilt Fatigue Scale-Adult version- 40 items. It has 4 sub-scales in Kannada was administered.	Total score (0 to 160) and subscale (Emotional, Social, Cognitive and Physical) scores (0 to 40).

3.3 Test environment

Preliminary interview and administration of the questionnaire were carried out in a well-lit, quiet room. Pure tone audiometry, immittance evaluation, OAE testing, and personal listening device output measurement were conducted in well-illuminated, air-conditioned, and sound-treated audiometric rooms that comply with the ANSI standards (ANSI/ASA S3.1-1999 (R2018) - Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms, n.d.). The dual task paradigm was done in a quiet room using the personal computer.

3.4 Data Analysis

The obtained raw data were subjected to statistical analysis using SPSS (statistical package for social sciences) software version 26. The descriptive statistics was done for both the group that is music listners and non-music listners to estimate mean, median, standard deviation inter-quartile deviation, minimum, and maximum values for secondary task scores of dual task paradigm, Vanderbilt fatigue scale adult 40 and oto-acoustic emissions. The data obtained from music listeners group and non-music listeners group were compared in study.

a) Listening effort analyzed using dual task paradigm (secondary task scores) in three different SNRs (+6, 0 -, and – 6 dB SNR)

b) Listening fatigue analysed using Vanderbilt fatigue scale adult 40

c) Correlation between scores on the secondary task of Dual Task Paradigm and VFS-A Checklist

d) Changes in OAE amplitude at low frequencies, high frequencies and for overall amplitude.

Chapter IV

RESULTS

The study aimed to investigate whether listening to high levels of music over an extended period of time will lead to increased listening effort and fatigue. The hypotheses evaluated that 'there is no significant effect of music exposure on listening effort and listening related fatigue'.

To test the hypotheses, music listeners' and non-music listeners' performance on the secondary task of a Dual Task Paradigm (DTP) test and their scores on the Vanderbilt Fatigue Scale-Adult version (VFS-A) were compared. Otoacoustic emissions amplitudes were compared between the groups. Additionally, participants' response was obtained to the question "Do you experience difficulty understanding speech in the presence of noise?" None of the participants reported of any difficulty while listening to speech in noise.

The data on the other tests were statistically analysed to meet the study objectives, using SPSS software version 26 (SPSS Inc, Chicago,USA). Shapiro-Wilk test of normality was used to assess the distribution of the data. Where the data were normally distributed ($p>0.05$), parametric tests were used for comparisons, and where the data were non-normally distributed ($p<0.05$), non-parametric tests were used for the comparisons. The results are presented under the following headings:

4.1 Comparison of listening effort between music-listeners and non-music listeners groups at different SNRs

4.2 Comparison of listening-related fatigue between music-listeners and non-music listeners groups

4.3 Comparison of OAE amplitudes between music-listeners and non-music listeners groups

4.4 Correlation between scores on the secondary task of Dual Task Paradigm and VFS-A Checklist

4.1 Comparison of Listening Effort between Music-Listeners and Non-music Listeners groups at Different SNRs

The median, minimum, maximum, and inter-quartile range values of scores obtained by the non-music listener and music listener groups on the secondary task of the DTP at three different SNRs (-6, 0 and +6 dB) are shown in Figure 4.1. In general, the scores were more for music listening group than for non-music listening group. The dual task paradigm for +6dB SNR ranged from 19 to 25 for non-music listening group and 16 to 23 for music listening group; for 0dB SNR it ranged from 18 to 25 non music listening group and 15 to 22 for music listening group; for -6dB SNR it ranged from 16 to 24 for non-music listening group and 14to 20 for music listening group.

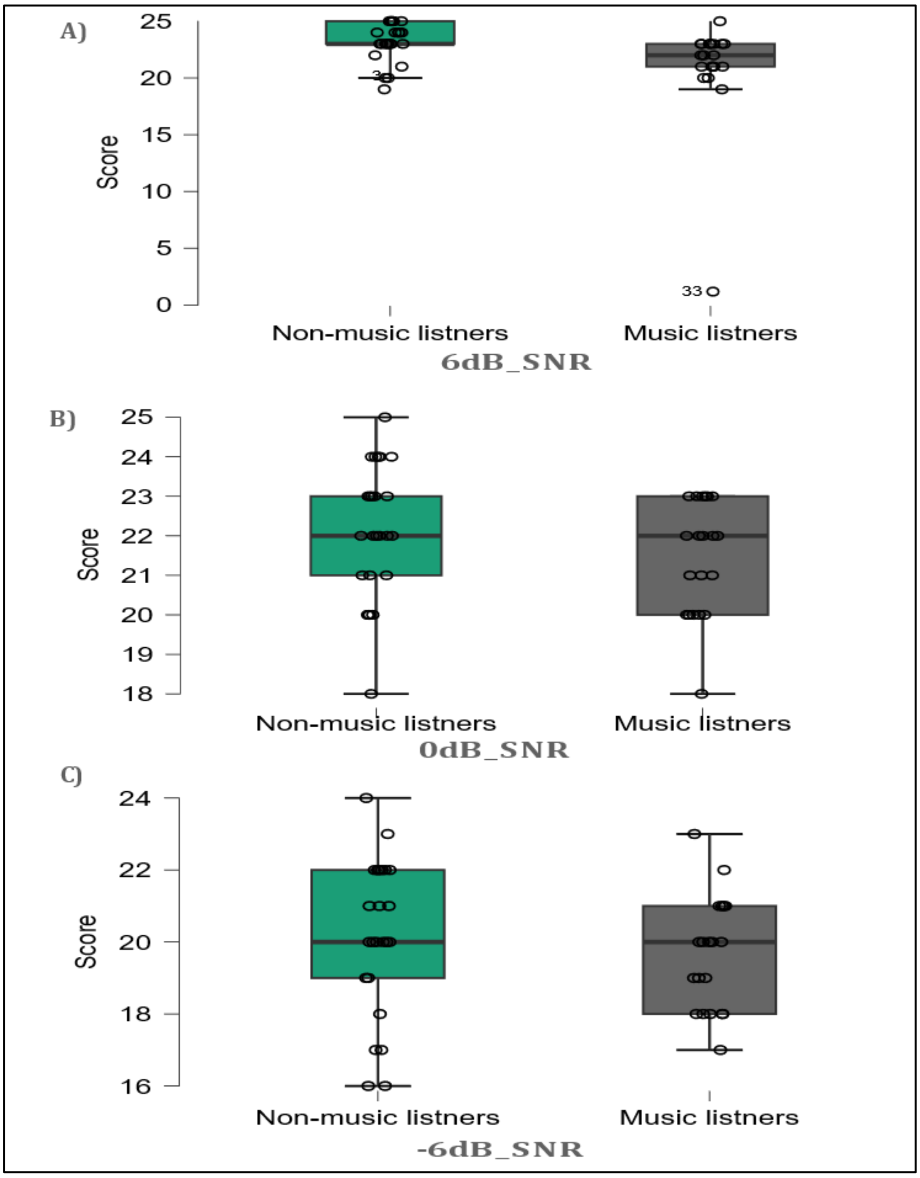

Figure 4.1: The median, minimum, maximum, and inter quartile range of scores obtained by the non-music listners and music listners groups on the secondary task of the DTP at 6dB SNR (A), 0dB SNR (B), and -6 dB SNR (C).

The scores were compared between the two groups separately for the three SNRs. The data were normally distributed (Shapiro-Wilks $p>0.05$) at -6 dB SNR (music listeners group: mean: 19.650, SD:1.565; non-music listeners group: mean :20.24, SD:2.146) and therefore the independent t-test was used for the comparison in this condition. There was no significant difference between the scores obtained by the two groups at this SNR (t=1.029, df =43, p = 0.309). The data were non-normally distributed (Shapiro-Wilks $p<0.05$) at +6 and 0dB SNRs and therefore the Mann-Whitney U test was used for the comparisons. The findings showed significant difference between the two groups in the scores obtained at +6dB SNR (*Z*=3.051, *p*=0.002). There was no significant difference at 0 dB SNR (*Z*=-1.422, p=0.155).

4.2 Comparison of listening-related fatigue between music-listeners and non-music listeners groups

The median, minimum, maximum, and inter quartile range of scores obtained by the non-music listeners and music listeners groups on the VFS-A 40 checklist on its four different subscales [Emotional (E), Social (S), Cognitive (C) and Physical (P)] and total VFS-A 40 are shown in Figure 4.2. The VFS-A 40 total score ranged from 0 to 17 for non-music listening group and 0 to 40 for Music listening group. The scores were more for music listening group than for non-music listening group.

The scores were compared between the two groups separately for the four subscales and the total VFS-A40 score. The data were non-normally distributed (Shapiro-Wilks *p<0.05*) and therefore the Mann-Whitney test was used for the comparisons. The findings showed significant difference between the two groups in the scores obtained for the different subsections and the total VFS-A40 score (Table 4.1).

Table 4.1.

Results of Mann-Whitney U test for subscale scores and the overall score on the VFS A-40 questionnaire between music listeners and non-music listeners groups.

Variables	**Z**	**Sig**
VFS A-40 Cognitive subscale	-3.374	.001
VFS A-40 Social subscale	-3.288	.001
VFS A-40 Emotional	-2.841	.004
VFS A-40 Physical	-3.292	.001
VFS TOTAL	-3.423	.001

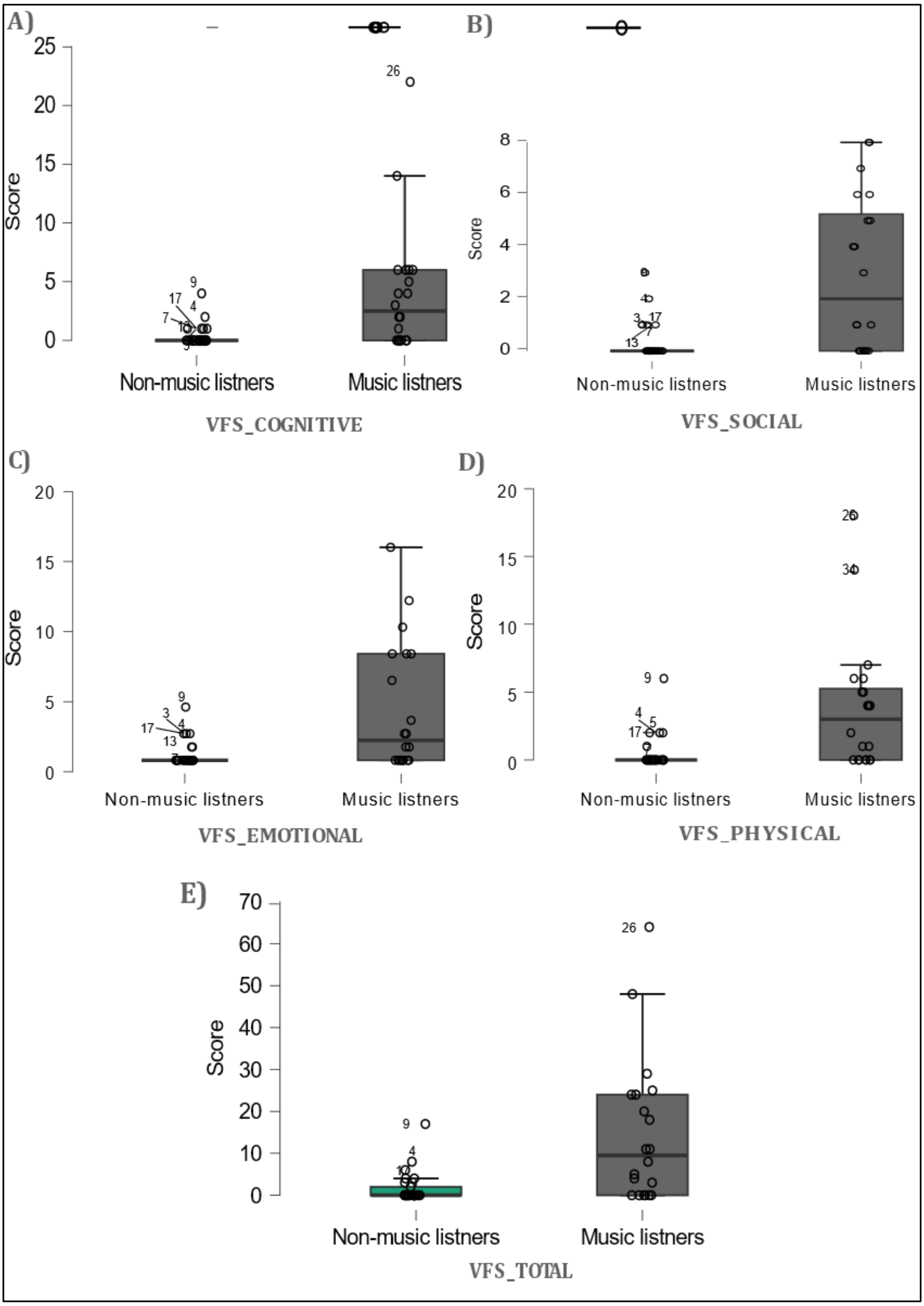

Figure 4.2. The, median, minimum, maximum, and inter quartile range of scores obtained by the non-music listners and music listners groups on the VFS_A-40(COGNITIVE)(A), VFS_A-40(SOCIAL) (B), VFS_A-40 (EMOTIONAL)(C), VFS_A-40 (PHYSICAL)(D) and VFS_A-40(TOTAL) (E).

4.3 Comparison of OAE amplitudes between music-listeners and non-music listeners groups

OAE amplitudes were averaged between 850Hz to 3500 Hz frequencies and named as low frequency average. OAE amplitudes were averaged between 4000Hz to 9500Hz frequencies and named as- high frequency average. The average of OAE amplitudes across all the measured frequencies was also calculated. All three amplitude measures were compared between the groups. In general, the low frequency average amplitude was lower in music listener group.

The median, minimum, maximum, and inter quartile range of OAE amplitudes obtained in the participant groups are given in Figure 4.3. The data were normally distributed (Shapiro-Wilks *p>0.05*) for all the frequency averages (mean, SD..) except for High frequency average and the overall amplitude average in the left ear. The results of t-test for group comparisons for the normally distributed data and Mann-Whitney for the non-normally distributed data are given in Table 4.2.

Table 4.2.

Results of t-test and Mann-Whitney test for comparisons of OAE averages for low frequency, high frequency and overall, between the music listeners and non-music listeners groups.

PARAMETERS	t	df	Z	Sig.(2-tailed)
OAE_HFA_R	.140	43		.889
OAE_HFA_L	-.114	43	-.114	.909
OAE_LFA_R	2.101	43		.042
OAE_LFA_L	2.417	43		.020
OAE_Overall_R	1.369	43		.178
OAE_Overall_L	-.434	43	-.434	.664

Note. p > 0.05 indicated in shaded area

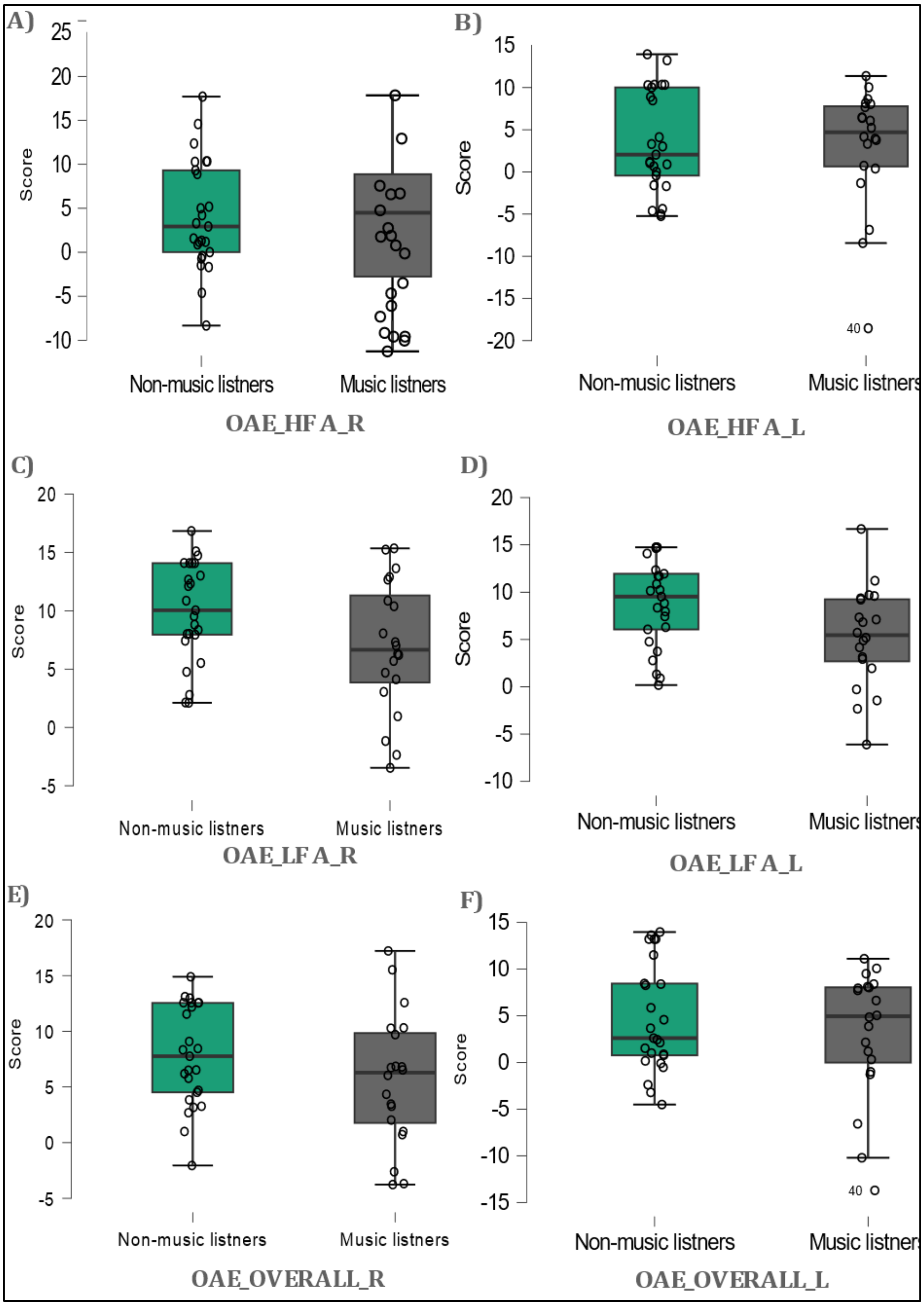

Figure 4.3. The median, minimum, maximum, and inter quartile range of average OAE amplitudes obtained by the non-music listners and music listners groups at high frequencies in the right ear [OAE_HFA_R(A)] and left ear [.OAE_HFA_L (B)], low frequencies in the right ear. (OAE_LFA_R (C)) and left ear (OAE_LFA_L (D)), overall, in the right ear (OAE_OVERALL_R(E) and left ear (OAE_OVERALL_L(F)

4.4 Correlation between scores on the secondary task of Dual Task Paradigm and VFS-A Checklist

The relationship between the scores of the secondary task in the dual task paradigm (assessing listening effort) and the total scores obtained from the VFS-A40 checklist (assessing listening fatigue) was examined using the Spearman correlation coefficient. The results of this analysis indicated a low negative correlation between the secondary task scores and VFS-A40 in all parameters in non-music listners. But negative correlation was observed only between DTP scores at 0 dB SNR and all subscales of VFS-A40 in the music listener group (Tables 4.3 and 4.4).

Table 4.3.

Result of Spearman correlation test between Vanderbilt fatigue scale adult-40 and dual task paradigm in non-music listners.

VARIBLES		DTP +6dB	DTP 0dB	DTP-6dB
VFS A-40 COGNITIVE SUBSCALES	Correlation coefficient	-.200	-.244	-.133
	Significance	.337	.240	.528
VFS A-40 SOCIAL SUBSCALES	Correlation coefficient	-.200	-.244	-.133
	Significance	.337	.240	.528
VFS A-40 EMOTIONALSUBSCALES	Correlation coefficient	-.239	-.269	-.134
	Significance	.250	.193	.524
VFS A-40 PHYSICAL SUBSCALES	Correlation coefficient	-.128	-.300	.078
	Significance	.542	.146	.711
VFS A-40 TOTAL	Correlation coefficient	-185	-.227	-.050
	Significance	.377	.275	.814

Table 4.4.

Result of Spearman correlation test between Vanderbilt fatigue scale adult-40 and dual task paradigm in music listners.

VARIBLES		DTP +6dB	DTP 0dB	DTP-6dB
VFS A-40 COGNITIVE SUBSCALES	Correlation coefficient	-0.045	-0.023	0.030
	Significance	0.770	0.145	0.845
VFS A-40 SOCIAL SUBSCALES	Correlation coefficient	-0.065	-0.181	0.048
	Significance	0.721	0.239	0.757
VFS A-40 EMOTIONALSUBSCALES	Correlation coefficient	-0.065	-0.270	0.016
	Significance	0.673	0.076	0.919
VFS A-40 PHYSICAL SUBSCALES	Correlation coefficient	-0.068	-0.344	0.111
	Significance	0.707	0.022	0.475
VFS A-40 TOTAL	Correlation coefficient	-0.000	-0.251	0.083
	Significance	0.844	0.100	0.686

Chapter V

Discussion

Speech perception is an active process that depends upon the acuity of the peripheral and central auditory system as well as the cognitive correlates of speech understanding. Any damage to even a single component mentioned can adversely affect speech understanding. Even in the absence of peripheral hearing loss, any damage to the processing abilities of the auditory system, or changes in the allocation of cognitive capacities for speech perception can adversely affect an individual's abilities to communicate. Measuring oto-acoustic emissions (OAEs) can reveal any subtle damage to the peripheral auditory system. Listening effort and listening-related fatigue may be metrics of any effects on the cognitive correlates of speech understanding in individuals without any explicit hearing loss.

The study aimed to compare listening effort, listening related fatigue, and OAE amplitudes between music listeners and non-music listeners. Listening effort was measured as scores obtained on secondary task in dual task paradigm (DTP), listening related fatigue was measured using the Vanderbilt fatigue scale -Adult 40 (VFS-A 40) questionnaire, and OAE amplitudes were calculated as low frequency average, high frequency average and overall average of Distortion Product OAE (DPOAE) amplitudes.

The first objective of the study was to compare the listening effort between music-listeners and non-music listeners. Since an individual's concern regarding difficulties in speech perception is usually the reason for an audiological evaluation and subsequent intervention, participants' experience of speech perception in noise was recorded. The participants in either group of the study did not perceive any difficulty to understand speech in the presence of noise. Following this, their performance was assessed on the DTP. The scores on secondary task of DTP obtained by music listeners were slightly lower compared to non-music listeners. This was true for all three Signal-to-Noise Ratios (SNRs)

- +6, 0, and -6dB SNR. However, the difference observed was not significant. The scores did not vary much between the test conditions either. Therefore, participants' perception was supported by the objective measure of listening effort.

The second objective of the study was to compare the listening-related fatigue among music listener and non-music listener groups, using the VFS-A 40 questionnaire. The scores on the questionnaire were significantly higher in the music-listeners group. This finding was in the absence of any significant listening effort – either perceived, or in a test. Hearing loss may increase the listening effort and fatigue due to increased attentional resources required to understand the degraded messages (Alhanbali et al., 2017). In the absence of hearing loss, this increased listening-related fatigue also indicates the degradation of certain processes in the auditory system necessary to understand speech. It also indicates that measures of listening effort fatigue could be a useful addition to the test battery when assessing the effects of prolonged exposure to loud music.

Kumar et al. (2012) observed that even in the absence of hearing loss, individuals who were exposed to noise levels above 90 dBA experienced difficulty in understanding speech, and performed poorly in working memory tests. Reduced temporal processing skills and need for increased allocation of cognitive capacities may result in increased listening effort (Shetty et al., 2022). However, in the current study, in the absence of hearing loss and any measurable listening effort, the participants in the music-listener group perceived listening-related fatigue. This may indicate that fatigue may be an early indicator of difficulties in speech perception. However, no direct correlation can be made unless the same participants are followed up and their listening effort and hearing thresholds are monitored over time, or a similar cross-sectional study is conducted for the purpose.

The third objective of the study was to compare the OAE amplitudes among music-listeners and non-music listeners. The DPOAE amplitudes at low frequencies were significantly lower in the music listeners group and there was no such difference seen for the high frequency average or the overall amplitude average. Studies have been done to check the effect of prolonged music exposure on OAE and PTA, and the results are inconclusive.

Kumar et al. (2009) examined the impact of Portable Music Systems (PMS) on hearing by comparing individuals who used PMS with age-matched controls who did not. They also explored the relationship between output sound levels and hearing measures. Among the 70 young adults studied, around 30% exceeded recommended safe listening levels. The study found no significant differences in mean pure tone thresholds or DPOAE amplitudes between PMS users and non-users. However, a positive correlation was observed between hearing thresholds and music volume, indicating that higher volume was associated with poorer hearing, while DPOAE responses showed a negative correlation with music volume, suggesting that higher volume was linked to reduced DPOAE levels.

In contrast, a study by Torre et al. (2013) found no statistically significant impact on PTA, TEOAEs, or DPOAEs as a result of exposure to amplified music. Additionally, there were no significant differences in OAE parameters between the initial test and subsequent tests in this study. Therefore, this study concludes that, based on the standard TEOAE and DPOAE tests, there is no observable effect on the participants' auditory system caused by the exposure to music. These findings align with a recent study they also observed no significant changes in DPOAEs within the 1–6 kHz range.

In a study by Hamdan et al., (2008) involving professional singers with normal hearing thresholds, researchers found that TEOAE responses were detectable but weaker compared to individuals with normal hearing. This suggests that some professional singers with apparently normal hearing may have subtle cochlear dysfunction that can be identified through TEOAE measurements. Additionally, the study emphasizes the significance of the criteria used to determine "at-risk" ears for music-induced hearing loss, showing that the choice of criteria can impact the number of identified cases. However, it's important to note that these findings are preliminary and require further research for a comprehensive understanding.

While some studies state that the physiological changes which will be made by music will be very minimal to estimate with usual audiological procedures like OAE and PTA (Job et al., 2009), others claim that high frequency OAE and high frequency audiometry can be used to identify the effects of prolonged exposure to noise early (Škerková et al., 2021). In a recent study Degeest et al. (2022) measured DPOAEs, TEOAEs, and DTP among individuals exposed to different levels of noise. They observed increased effort and more absent OAEs with when exposed to higher levels of noise. In the current study, differences were seen in OAEs only at the low frequencies. This could be in line with the literature that reports inconsistencies in the impact of long-term exposure to music on OAEs. Perhaps in individuals with longer exposure durations and higher levels of exposure, the effect on OAEs might be more pronounced.

The findings of the study indicate that there could be an effect of exposure to loud music for prolonged duration. However, this was evident only in the measures of listening related fatigue. Similar to the present study's findings, the reports in literature are also inconclusive regarding the effect of noise/music exposure on OAEs. From the current study's findings, it may be recommended to include a measure of listening fatigue to understand the early effects of prolonged exposure to music.

Finally, based on the findings of the present study:

1. We failed to reject the hypothesis as there is no significant difference in listening effort between the music listners and non-music listners.

2. We rejected the hypothesis as there is no significant difference in listening fatigue between the music listners and non-music listners.
3. We partially rejected the hypothesis as there is no difference in OAE amplitudes between the music listners and non-music listners.

Chapter VI

Summary and Conclusion

The study aimed to investigate whether listening to high levels of music over an extended period of time will lead to increased listening effort and fatigue. Listening effort was measured as scores obtained on the secondary task of a Dual Task Paradigm (DTP) test and listening related fatigue was measured as the scores obtained on the Vanderbilt Fatigue Scale-Adult version (VFS-A 40) in Kannada. Otoacoustic emissions were used as a measure of the extent of physiological damage to the OHCs among the participants in the music listeners and non-music listeners groups. Output levels from the personal listening devices of the participants in the music listeners group was also obtained.

Objectives of the study were:

1. To compare listening effort between individuals with and without prolonged exposure to high levels of music using the dual task paradigm.
2. To compare listening related fatigue between individuals with and without prolonged exposure to high levels of music, using VFS-A-40 questionnaire.
3. To compare the DPOAE amplitude levels between individuals with and without prolonged exposure to high levels of music.

There was significant difference between the groups in VFS-A40 scores in all the domains, and for low frequency average of the DPOAE amplitudes. The study concludes that individuals with exposure to loud music for prolonged period of time experience listening related fatigue despite having normal hearing sensitivity. This indicates that fatigue measures might be more sensitive to early detect the effects of exposure to noise.

Implications of the Study

Hearing loss and other related difficulties due to exposure to recreational noise is a modifiable cause. Listening related fatigue may be observed in individuals with exposure to hazardous levels of noise, or in this case- high levels of music, even before any clinical manifestation. If individuals with prolonged exposure to high levels of recreational noise are revealed to experience significant amounts of listening effort and fatigue, this information can be used for counselling and awareness creation. Also, the information can be used for policy making and setting of standards in the personal listening devices related to the loudness and duration of auditory signals presented. A better understanding of preclinical symptoms in individuals who have been exposed to loud music for a prolonged period of time, even in the absence of hearing-related and speech-processing issues, can be gained through this study. This study can also be used to develop predictive tools for investigating preclinical symptoms in individuals who have been exposed to unsafe levels of music."

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