Does prolonged exposure to noise levels below damage risk criteria increase listening effort and fatigue?

Renuka Prasad S. B.

Registration No: P01II21S0068

This Dissertation is submitted as a part of fulfilment for the

Degree of Master of Science (Audiology)

University of Mysore, Mysuru

ALL INDIA INSTITUTE OF SPEECH AND HEARING,

MANASAGANGOTHRI, MYSURU -570006

SEPTEMBER 2023

CERTIFICATE

This is to certify that this dissertation entitled '**Does prolonged exposure to noise levels below damage risk criteria increase listening effort and fatigue?** is a bonafide work submitted in part fulfilment for degree of Master of Science (Audiology) of the student Registration Number: P01II21S0068. 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.

Mysuru,

September 2023

Dr. M. Pushpavathi

Director

All India Institute of Speech and Hearing,

Manasagangothri, Mysuru-570 006

CERTIFICATE

This is to certify that this dissertation entitled '**Does prolonged exposure to noise levels below damage risk criteria increase listening effort and fatigue?** has been prepared under my supervision and guidance. It is also been certified that this dissertation has not been submitted earlier to any other Universityfor the award of any other Diploma or Degree.

Mysuru,

September 2023

Ms. Indira C.P.
Guide
Asst. Professor of Audiology
All India Institute of Speech and Hearing,
Manasagangothri, Mysuru-570 006

DECLARATION

This dissertation titled ‘**Does prolonged exposure to noise levels below damage risk criteria 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.

Mysuru

September, 2023

Register Number: P01II21S0068

Acknowledgment

First and foremost, I would like to express my gratitude to Almighty **God**. Everything I have accomplished is by His will and divine support.

I am profoundly grateful to my mother(Mrs.**Sharanamma**), and my father(**Mr.Sharanayya Swami**), for their unending love, guidance, sacrifices, and unwavering support. I want to express my heartfelt appreciation for your continuous understanding, patience, and for fulfilling my endless wishes, for which I can never fully repay you. I will forever carry a deep sense of gratitude for the life you've provided me. Your constant support throughout this journey has been crucial, and I can't imagine my life without you by my side.

My dear sister **Soubhagya**, you are my true motivation for hard work. I haven't seen anyone working harder than you. We are always proud of you, the shining light of our home. And my little brother **Veerendra**, we all love you dear.

I extend my profound gratitude to my guide, **Ms. Indira C. P.**, for her unwavering support and guidance throughout my dissertation. When I started, I had little knowledge of research, but you patiently taught me everything. You were always available to help with our doubts and correct our mistakes with a smile on your face. Your energy was constant, and your dedication was remarkable. You taught me every aspect of our dissertation, and I never expected to learn this much. Your creativity and encouragement pushed us to do our best, and without your humble support, this achievement would not have been possible. We consider ourselves fortunate to be your first students in this dissertation journey.

My Data collection went smoothly, thanks to **Pushkal Anna**, who helped me obtain permission for testing at your workplace. You were also by my side during data collection, making it possible. Your contribution to my dissertation is immense, and without you, data collection would not have been possible. I am thankful for your entire family, including **Sanvi, Ms. Pratibha Jain, Deepika** akka and the little human, **Arnav**.

A special thanks to **Sanvi** for all her support, guidance and counseling- Best Friends Forever.

I would like to express my gratitude to **Dr. Hari Prakash** for his assistance with the questionnaire.

I am grateful to **Dr. Hornsby** for his contributions to the field of listening effort and fatigue research.

I am thankful to Sandeep sir for granting me permission to access the instruments.

I would like to express my gratitude towards **Guru Vignesh sir** for his cooperation in providing the instruments and his guidance in this dissertation.

I would like to thank **Sanjay Anna** for assisting me with instrument use and providing valuable inputs.

I am thankful to Vasantha Lakshmi Mam for her assistance with statistics.

I express my deep appreciation to **all the participants** who wholeheartedly engaged in the study. None of this would have been achievable without each and every one of you.

I am always grateful to have a brother like you, **Karthik**, who has consistently guided me on the right path and helped me to make correct decisions. Your counseling during difficult times and your willingness to listen to my problems mean a lot to me. I consider myself fortunate to have you in my life, **brother**.

To my dear **Harsha anna**, my well-wisher, my guide, my support, and my strength, thank you for everything. **Brothers for life!**

I am grateful to have the best gang **We6(SAP)- Sanvi, Sharath, Shashank, Amrutha, and Shreya**. Friends forever!

Thanks to the Spoilers for the memories we've created - **Sumanth MC, Uday, Varsha, Teenu, Rohini**.

I am thankful to **Varsha R** for your constant support and guidance at AIISH. This will remain forever.

I am thankful to my dissertation partner and riding buddy, **Sumanth MC**, for making my days better at AIISH. Here's to many more rides to come.

Sumanth MC, Shashank, Uday, Maltesh, Gagan, and Prasanna - the m emories we have made will be remembered for a lifetime."

Thanks to my clinical partner, **Mani**, who adjusted himself for my sake and also helped me out with my dissertation. A true and good friend.

Gratitude to the wonderful junior, **Manu**.

Thank you, **Nishant** ,**Suraj**,and **Ankit** for helping me with installing software and resolving my issues.

Last but not the least, I would like to thank my PG batchmates **Resonators**

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Abstract

Background: Exposure to hazardous levels of noise is a major aetiology of disabling hearing loss. The impact of noise exposure is seen even in individuals exposed to noise levels considered safe for human listening (Thompson et al., 2022). Maruthy et al. (2018) reported that individuals exposed to noise levels below DRC experience poor stream segregation and working memory skills. These individuals may also be experiencing increased listening effort and subsequent listening fatigue. However, no empirical evidence exists to prove the same.

Aim: The study aimed to understand listening-related effort and fatigue in individuals exposed to noise levels below damage risk criteria.

Method: A total of 48 individuals in the age range of 18 to 50 years participated in the study. They were divided into two groups – the Noise Exposed Group and the Noise Unexposed Group. Data collection was carried out in three steps. measurement of ambient noise, gathering demographic information, and audiological evaluation and measurement of listening effort and fatigue. Listening effort was measured using dual task paradigm and listening fatigue was measured using Vanderbilt Fatigue Scale-Adult version-40 items (VFS-A-40) in Kannada.

Results: The result revealed that there was a significant difference in listening effort and fatigue between the noise-exposed group and the noise-unexposed group.

Conclusion: Prolonged exposure to noise level below Damage risk Criteria can also result in increased listening effort and fatigue. This could possibly be the result of deficits in higher auditory processing due to prolonged exposure to noise.

Chapter 1

Introduction

Exposure to hazardous levels of noise is a major aetiology of disabling hearing loss. Individuals with exposure to noise experience auditory effects like hearing loss and tinnitus and non-auditory effects like increased stress, sleeping difficulties, and cardiovascular problems (Basner et al., 2014). Exposure to moderate levels of noise too is reported to cause anatomical and physiological changes, or 'hidden hearing loss' in animal models (Lin et al., 2011; Lobarinas et al., 2017). In these studies, the participants had reduced amplitude of wave I of the ABR post exposure to noise, which is indicative of reduced synchrony of auditory nerve fibres, or of reduced number of fibres responding to sound.

Human beings also experience changes in the auditory responses after exposure to noise, including reduced neural responses to sounds (Bressler et al., 2017). Reduced neural responses to sounds post noise exposure is reported to cause difficulties in speech perception, especially in the presence of noise, due to altered coding of temporal and intensity features of the signals (Kohrman et al., 2020).

Exposure to noise is also reported to cause impairments in the cognitive domain. For example, individuals with Noise induced hearing loss(NIHL) had longer reaction time and increased errors during tests like simple reaction time test, choice reaction time test, and stroop test (Dudek et al., 1991). Anatomical changes related to cognitive dysfunction due to long term exposure to noise include amyloid- **β** deposition, and tau hyperphosphorylation on several parts of brain like hippocampus and cortex (Huang et al., 2021). Exposure to everyday environmental noise that is well below the damage risk criteria (DRC) is also associated with poorer reading comprehension and language skills in children and cognitive impairment in older individuals (Thompson et al., 2022).

Considering the propensity of individuals exposed to noise to be at risk for cognitive impairment, they may have a cumulative effect of noise and cognitive load leading to increased listening effort. Listening effort refers to the cognitive resources allocated to understand a spoken or auditory message (Pichora-fuller et al., 2016). Listening effort is more while listening to degraded auditory stimuli, at the level of the signal or the individual. Predictably, increased listening effort is reported in individuals with noise induced hearing loss (Wieczerzak et al., 2021).

Listening effort can be studied using subjective measures like questionnaires, objective measures like pupillometry, electrophysiology, and behavioural measures like dual task paradigm (Colby & McMurray, 2021). Dual task paradigm with primary and secondary tasks have been extensively used to study listening effort in individuals with noise induced hearing loss (Picou & Ricketts, 2014).

A difficulty in hearing can lead to listening related fatigue in situations demanding communication, due to near-constant exertion of listening effort (Alhanbali et al., 2017). Listening fatigue may be measured by means of reaction time in dual task paradigms and single task paradigms, self-reported measures, and questionnaires.

1.1. Need for the Study

The impact of noise exposure is seen even in individuals exposed to noise levels considered safe for human listening (Thompson et al., 2022). Maruthy et al. (2018) reported that individuals exposed to noise levels below DRC experience poor stream segregation and working memory skills. These individuals may also be experiencing increased listening effort and subsequent listening fatigue. However, no empirical evidence exists to prove the same. While factors related to working memory and speech perception are examined in the population, the impact of the same in their daily life remains unexplored. An exploration of the impact of prolonged exposure to below DRC levels of noise may be useful in establishing the accepted levels of noise in areas of human habitation and also in sensitizing individuals exposed to noise on a regular basis.

1.2. **Aim of the Study**

The study aimed to understand listening-related effort and fatigue in individuals exposed to noise levels below damage risk criteria.

1.3. **Objectives**

The objectives of the study were to compare:

1. The listening effort between individuals with and without prolonged exposure to noise below DRC using a dual task paradigm.
2. The listening-related fatigue between individuals with and without prolonged exposure to noise below DRC, using the Vanderbilt Fatigue Scale-Adult version-40 items (VFS-A-40) in Kannada.

1.4 **Hypotheses**

The hypotheses tested by the study were:

1. There is no significant effect of noise exposure below DRC on listening effort.

2. There is no significant effect of noise exposure below DRC on listening related fatigue.

Chapter 2

Review of Literature

The review of literature is arranged under the following headings:

2.1 Effect of noise below damage risk criteria on animals and human beings

2.2 Listening effort and fatigue in individuals with hearing impairment and those with normal hearing

2.3 Methods for measuring listening effort and listening-related fatigue

2.1 Effect of noise below damage risk criteria on animals and humans

The effects of noise below Damage Risk Criteria (DRC) were studied in both animal and human models. The studies carried out on animals provide physiological and histopathological evidence to the effect of noise and those carried out in human beings mostly give information regarding the behavioural and physiological manifestations of exposure to noise. These studies will be discussed under separate sections.

2.1.1 *Studies on animal models:*

In a study conducted by Lin et al. in 2011, mice were exposed to noise in the frequency range of 8-16 kHz at a loudness level of 100 dB SPL for a duration of 2 hours. These levels were below their damage risk criteria. After 24 hours of this exposure to noise, the researchers recorded the auditory brainstem responses and recorded otoacoustic emissions from the mice. They observed elevated hearing thresholds in the mice in both measures. The thresholds of auditory brainstem responses were elevated by 40 dB at higher frequencies, which was significant. Additionally, there was a smaller increase in threshold levels in distortion product otoacoustic emissions. Suprathreshold DPOAE measurements indicate a restoration of values comparable to those before exposure, implying a functional recovery of the outer hair cells. The hearing thresholds returned to their normal levels after a period of 2 weeks following the noise exposure. However, even though the thresholds returned to normal, the suprathreshold measures to sounds continued to be impaired. The authors attribute this finding to a loss of neurons in certain regions of the cochlea. They speculated that ‘synaptopathy’, or a substantial degeneration of pre-synaptic and post-synaptic elements in the inner hair cell region could have led to this loss of neurons.

In a study by Noreña et al. in 2006, young cats were exposed to a series of tone pips spanning 32 different frequencies, ranging from 5 to 20 kHz. These tones were randomly presented at an average rate of 96 times per second, with a loudness level of 80 dB SPL, and were continuously stimulated for 24 hours every day over a duration of 5 months.. After thus extended exposure period researchers measured Local field potentials (LFPs) simultaneously with the Multiunit activity(MUA) recordings from the same electrodes. They observed that the way the auditory cortex represented these exposed frequencies was less accurate, and there was a subsequent reorganization in the cortical regions responsible for processing these tones.

In a similar study, Pienkowski et. al. (2011) found comparable outcomes in adult cats, even at lower noise levels of 68 dB SPL. During their research, adult cats were exposed to band-limited sound combinations daily for 6 weeks, with daily exposure of 12 hours. It is noteworthy that both studies observed similar effects on the auditory system, despite the absence of any peripheral hearing loss in the subjects.

In a study conducted by Zhou and Merzenich in 2012, Adult rats were exposed to controlled noise at a level of 65 dB SPL for a continuous period of Two months, 24 hours a day which is below the safety standard for noise exposure. The researchers measured ABR thresholds on the rats after the noise exposure. The findings revealed no effect on the hearing sensitivity. Additionally the researchers measured Local field potentials (LFPs) on the rats after the noise exposure However, there were significant adverse effects at the level of the cortex. The effects persisted even when the rats were exposed to the noise for 10 hours daily. These findings indicate that consistent exposure to even low level continuous environmental noise, for extended periods of time can adversely affect the auditory system.

2.1.2 *Studies on human beings:*

Kumar et al. (2012) assessed the temporal processing abilities and speech perception in noise (SPIN) of train drivers with normal hearing who were regularly exposed to the occupational noise of engines for about 8-10 hours a day for a period of more than 10 years. The noise exposure levels were Leq of 86 dBA. The study's findings showed that the participants in the experimental group had poor perception of speech in the presence of noise, even though their hearing thresholds were normal on pure tone audiometry. They also had poor temporal processing skills. Their performance in tests of temporal processing was reported to be connected to their reduced ability to understand speech in noisy environments. Ganesan and Kumar (2012) studied speech perception in noise abilities in individuals who regularly used personal music systems. They found that regular use of personal music systems caused a decline in speech perception abilities in noisy environments.

As reported by Maruthy et al. (2018) shopkeepers with hearing thresholds below 15 dBHL were subjected to average environmental noise levels (Leq) of 76.5 dBA which was well below the DRC. The researcher measured auditory and cognitive abilities, including speech perception in noisy environments, acceptable noise levels, concurrent vowel identification for auditory assessment, and Operation SPAN and Backward Digit Span for cognitive assessment. The results indicated that shopkeepers exhibited significantly poorer auditory stream segregation abilities and working memory capacities. In a recent meta-analysis of articles that have assessed the impact of environmental noise on human cognition, Thompson et. al. (2022) report that cognitive capacities related to executive function are affected in children exposed to higher levels of environmental noise. Though they mention that the evidence is poor from the studies conducted, the study also indicates that noise influences human cognitive processing.

These findings, in conjunction with the studies conducted in animals, collectively demonstrate that prolonged exposure to noise, be it above or below the levels that are reported to be hazardous, can have a lasting impact on higher-order auditory processing abilities. Importantly, these effects are observed even in the absence of documentable change in the individuals' thresholds of audibility. The exposure to such noises is highly prevalent in the current societies, either as recreational or occupational noises.

2.2 Listening effort and Listening fatigue

Cognitive resources are limited, and are shared between tasks that require cognitive processing, including listening. Listening in degraded environments, or listening while having difficulties in auditory processing tends to demand more allocation of the cognitive resources, and thus results in ‘listening effort’. Increased listening effort can result in listening-related fatigue, since one needs to expend more effort to execute other daily functions, aside from the increased effort applied to listening.

2.2.a Listening effort

Listening effort refers to the cognitive resource requirements necessary for an individual to understand speech (Desjardins & Doherty, 2014). Since cognitive resources are limited, listening effort may be termed as the amount of mental capacity a listening task demands and occupies in a system that is capacity-limited (Desjardins & Doherty, 2014).

It has been consistently observed that listeners exert more effort when faced with challenging listening situations compared to quiet ones, as reported by Gordon-Salant and Fitzgibbons in 1997.

In a study conducted by Desjardins and Doherty in 2012, researchers examined the concept of listening effort in a group of older individuals with hearing impairment who were using binaural amplification, a group of older individuals with normal hearing, and a group of younger individuals with normal hearing. They all performed a speech recognition task in noisy conditions. The findings from this study revealed that both groups of older participants, whether they had hearing impairment or normal hearing, expended significantly more effort in their listening during the speech-in-noise task when compared to the younger participants. This underscores the idea that age and hearing status can impact the amount of cognitive effort required to understand speech in challenging acoustic environments.

Gosselin & Gagné in 2010,as well as McGarrigle et . al. in 2014 assessed listening effort in individuals with simulated hearing loss. They observed longer reaction times in secondary tasks on a dual task paradigm after simulating hearing loss, which indicated a significant increase in listening effort in individuals with simulated hearing loss. Feuerstein's 1992 also demonstrated reduced ease of listening in among individuals with unilateral hearing loss.

Studies conducted on individuals with hearing loss have also demonstrated increased listening effort in the population(Shetty et al., 2022). Listening effort has been studied in individuals with hearing loss using pupillometry(Laeng et al., 2012).

Evidence from studies that have used these physiological measures indicate that hearing impairment can increase listening effort.

Exposure to higher levels of noise has been shown to have auditory as well as non-auditory effects. Shetty et al., (2022) studied listening effort in individuals who had been exposed to industrial noise levels exceeding 90 dB(A) for a minimum of 5 years, for at least eight hours daily, and in individuals with hearing loss, but in exposure to occupational noise. They used a Dual Task Paradigm to measure listening effort. All participants within the experimental and control groups had mild bilateral hearing loss. They observed increased listening effort in participants with noise exposure compared with individuals with hearing loss alone. This suggests that exposure to noise causes substantial challenges in temporal processing, resulting in heightened listening effort compared to those solely dealing with hearing loss.

There is no consistent finding to suggest that hearing aid amplification reduces listening effort (Ohlenforst et al., 2017). This indicates that correcting for audibility alone may not reduce listening effort, and that listening effort may be contributed to by factors related to higher order auditory processing.

2.2.b Listening-related fatigue

Subjective fatigue can be defined as a mood state associated with feelings of tiredness and exhaustion (Hornsby et al., 2021). Listening-related fatigue, also known as auditory fatigue, refers to a condition in which an individual experiences physical, mental, or emotional exhaustion as a result of sustained or intense listening or hearing activities (Holman et al. 2019). It is generally considered to be associated with listening effort.

Degraded acoustic conditions can have a detrimental impact on the speech-recognition performance of both children with normal hearing and those with hearing loss Finitzo-Hieber and Tillman (1978), and Nabelek and Pickett(1974). Hicks and Tharpe (2002) showed that children with hearing loss may need to expend greater effort and subsequently experience higher levels of fatigue compared to their counterparts with normal hearing when listening to speech in challenging conditions.

Everyday listening situations may be challenging for children with hearing loss, when the auditory information they receive is compromised by hearing impairment and background noise. To actively engage in listening under such conditions, they may need to exert a significant amount of listening effort. This sustained effortful listening, when experienced over time, can lead to feelings of fatigue (Hornsby et al., 2021).

In a study conducted by Burke and Naylor in 2020, they examined daily-life fatigue in44 individuals with mild to moderate hearing impairment aged between 46 and 77 years. Participants used a smartphone app called ecological momentary assessment (EMA) to answer Custom made questions. The findings revealed that both individuals with hearing impairments and those with normal hearing experienced increased fatigue as the day progressed, and this fatigue developed at a similar rate in both groups. It was also observed that challenging listening situations were relatively rare for both groups. However, there wasn't a clear link between specific listening situations and momentary fatigue. Instead, momentary fatigue was associated with the average level of listening activity and whether someone was engaged in a conversation. Interestingly, the presence of tinnitus was linked to higher momentary fatigue, even after accounting for other factors. Lastly, having a fatiguing health condition emerged as a significant predictor of both persistent and momentary fatigue.

2.3 Methods to measure listening effort and fatigue

There are different methods to study listening effort and fatigue.

2.3.a. listening effort

The effort expended during listening tasks can be assessed through various methods. Some of the most commonly utilized metrics for measuring listening effort, as described by Seeber in 2013include:

- Mathematical Models (Pass et al. in 2003). These models use mathematical equations to estimate the cognitive effort required for specific tasks or under particular conditions.
- Subjective Rating Scales of Perceived Cognitive Load (Rönnberg et al., 2014). These involve individuals self-assessing their own cognitive workload or effort during listening tasks. is an example of this approach.
- Behavioral Performance Methods, like the dual-task paradigm (Sarampalis et al., 2009). This method involves assessing an individual's performance on a secondary task while concurrently engaged in a listening task, with changes in performance indicating variations in cognitive effort.
- Physiological measures of listening effort capture changes in the activity of the central and autonomic nervous systems during task performance (McGarrigle et al., 2014). These measures provide insights into the mental processing involved in listening tasks. Some examples of physiological measures to assess listening effort are:
    - Electroencephalographic (EEG) Response: EEG measures the brain's electrical activity by placing electrodes on the scalp. It offers precise temporal markers of mental processing (Bernarding et al. in 2012 and Davis

et al. in 2021). It reveals the responses of the brain to acoustic stimuli that can provide insights into the cognitive effort required during listening tasks.

- Functional Magnetic Resonance Imaging (fMRI): fMRI measures changes in blood oxygenation levels, reflecting the metabolic consequences of neuronal activity. For instance, increased activity in specific brain regions, such as the left inferior frontal gyrus, can signify compensatory effort required during challenging listening tasks, including attention-demanding activities. Wild et al.'s study in 2012 is an example of using fMRI to explore listening effort.
- Pupillometry: Pupillometry involves measuring changes in pupil diameter, which is an indicator of mental activity intensity. For a task with cognitive load, the pupil tends to dilate until the task's demands exceed the available processing resources. Pupillometry has been used to assess changes in attention and perception during listening tasks (Laeng et al., 2012).

Dual task paradigm

The dual-task paradigm (DTP), originally proposed by Broadbent in 1958, is founded on the concept that the brain possesses limited capacity to process information from all sensory systems simultaneously. This cognitive capacity is allocated to different sensory systems based on their current demands. As the cognitive demands of one task increase, it consumes a larger portion of cognitive resources, thereby reducing the resources available for concurrent performance of a second task (Kahneman, 1973).

When there is a decrease in performance on the secondary task in response to increased demands on the primary task, this is interpreted as evidence of heightened cognitive effort, as noted by Rabbitt in 1968. In the context of auditory tasks, this increased cognitive effort is often referred to as heightened listening effort, as proposed by Downs in 1982, and supported by Anderson Gosselin and Gagné in 2011, as well as Desjardins and Doherty in 2014.

The DTP is one of the most commonly used behavioural measures to assess listening effort, as highlighted in studies by Gosselin and Gagné in 2011 and Desjardins and Doherty in 2013. In this paradigm, participants simultaneously perform a primary task, typically involving word or sentence recognition, and a secondary task. Secondary tasks can take various forms, such as probe reaction time tasks, memory tasks, tactile pattern recognition tasks, or even simulated driving, as exemplified in the research by Wu et al. in 2014.

The core principle of DTPs aligns with the theory of limited cognitive capacity, suggesting that an increase in cognitive effort or cognitive load due to the primary task's demands results in decreased performance on the secondary task, which is commonly interpreted as heightened listening effort. This paradigm provides valuable insights into how individuals allocate cognitive resources during complex auditory tasks.

b. Listening fatigue

The different measures to record listening fatigue are self-report measures and questionnaires. Self-report measures can be used to assess the experiences of effortful listening, distress, and fatigue. One commonly used method is the Visual Analog Scale (VAS). For a VAS, participants rate the level of effort required to perform listening tasks in different conditions, on a scale (example, from 1 to 10). This provides a subjective assessment of their perceived listening effort.

Additionally, other self-report measures could be single items taken from existing questionnaires that focus on aspects related to listening effort. Example is the lowest acceptable performance level self-report method developed by Boothroyd and

Schauer in 2015. It allows researchers to gain a better understanding of how individuals with hearing impairment perceive and respond to challenging listening situations, providing valuable qualitative data alongside quantitative assessments.

General fatigue measures like Profile of Mood States (POMS) have been used to study the impact of hearing loss on subjective feeling of vigour Dwyer et al. (2019). However, the POMS may not be sensitive enough to detect fatigue related to listening difficulties in individuals with hearing loss. There is evidence that listening-related fatigue is a significant issue for many people with hearing loss. It can affect their work performance and overall quality of life.

Later, a Patient-Reported Outcome Measure (PROM) was custom-designed to measure the extent of fatigue related to listening in individuals dealing with hearing impairments. A theoretical framework that aimed to understand the link between hearing loss, its psychosocial consequences, and the fatigue experienced during listening was constructed through several focus group discussions. They also developed the subjective assessment tool known as the Vanderbilt Fatigue Scale for Adults-40 (VFS-A-40).

In a study conducted by Hornsby and colleagues in 2021, they examined listening-related fatigue in 900 school-age children. These children had varying hearing conditions, including unilateral hearing loss, bilateral hearing loss, and no hearing loss. They used the Vanderbilt Fatigue Scale for Adults-40 (VFS-A-40) to assess fatigue levels, considering both self-reports from the children and proxy reports from their parents. The study revealed that children with hearing loss were more prone to experiencing listening-related fatigue. Importantly, this increased risk was consistently significant regardless of whether the hearing loss was unilateral or bilateral.

Chapter 3

METHODS

3.1 Research Design

A between-group comparison design was used to study the research objectives.

3.2 Participants

A total of 48 individuals in the age range of 18 to 50 years participated in the study. They were divided into two groups – the Noise Exposed Group and the Noise Unexposed Group. The Noise Exposed Group (n=23, aged between 23 to 46 years) was operationally defined as individuals working in environments with high levels of noise, but below the DRC [below 85dBA of 8-hour time-weighted average (8hr-TWA) with 3dB exchange rate] for over 5 years. The participants were recruited from the Government Divisional Press located in Saraswathipuram, Mysuru-570009. The noise levels measured in the area ranged from 67.4 to 71.4 dB. The Noise Unexposed Group (n=25 aged between 18 to 25 years) was operationally defined as individuals who were working in quiet environments, with noise levels lower than the Noise Exposed Group. The participants were recruited from the AllIndia Institute of Speech and Hearing (AIISH), Mysore campus, including students, multitasking staff, and security personnel of AIISH. The noise levels measured in the area ranged from 59.2 dB to 63.4 dB. All participants were fluent Kannada speakers, with education levels ranging from 10th Standard to Graduation. The participants had knowledge of other languages such as Hindi, English, and Telugu. All the participants had hearing sensitivity within normal limits (4 frequency PTA <25 dB) on pure tone audiometry, normal middle ear functioning (Type 'A' tympanogram with present reflexes), and no history of otological or neurological complaints. Informed consent was taken from all the participants before their participation in the study. Individuals exposed to noise levels above DRC were excluded from the study.

3.3 Procedure

Data collection was carried out in three steps - measurement of ambient noise in different locations to determine the ambient noise levels in Leq during peak hours, participant selection and audiological evaluation, and measurement of listening effort and fatigue. All the tests were carried out at the participant's workplace itself. A summary of all the tests carried out during the study are presented in table 3.1.

3.3.1 Measurement of ambient noise

Ambient noise levels were measured at three locations: the Government Divisional Press in Saraswathipuram, Mysuru; The South India Paper Mills LTD. (SIPM) in Nanjangudu; and AIISH, Mysore Campus. A calibrated Bruel and Kjaer 2270 Sound Level Meter (SLM) was used for these one-time measurements in each area. Prior to commencing the noise measurements, the SLM calibration was confirmed. The SLM settings were configured for Equivalent Continuous Sound Pressure Level (LAEq), A-weighting frequency response, and Fast time response. During the noise measurements, the SLM was positioned at a height of 1.2 meters above the ground and placed 3.5 meters away from any obstructing structure. These measurements were conducted during the peak work hours. The noise levels obtained in Leq were used to choose locations to approach prospective participants for the study. Individuals working in areas with noise levels below 80dB were taken for study. The noise level identified at The South India Paper Mills LTD. (SIPM) exceeded the permissible DRC so The South India Paper Mills LTD was not included in the study. However, the noise level at the Government Divisional Press in Saraswathipuram, Mysuru, ranged from 67.4 dB to 71.4 dB, making the workers in this area eligible for inclusion in the noise-exposed group. Similarly, the noise level identified at AIISH, Mysore Campus, fell within the range of 59.2 dB to 63.4 dB, making individuals at AIISH eligible for inclusion in the noise-unexposed group. Therefore, individuals working at the Government Divisional Press and AIISH were approached for participation in the study. In the Government Divisional Press, a total of 32 individuals were screened for participant selection in the noise-exposed group, of which 23 were eligible for the study. At the AIISH campus, 28 individuals were screened for participant selection in the noise-unexposed group, and 25 were found eligible for the study.

3.3.2 Participants selection

A custom-made questionnaire was used to gather demographic information, the duration of exposure to noise and ontological and neurological disorders. A detailed history was taken to rule out the history or complaint related to otological or neurological disorders. Following this, audiological evaluation was carried on the participants.

Audiological evaluation: All study participants had normal auditory system as assessed through auditory test battery. Audiological test battery included otoscopic examination, pure tone audiometry screening, tympanometry screening, and otoacoustic emission (OAE) screening.

- Otoscopic examination: Otoscopic examination was carried out to ensure the structural integrity of the ear canal and tympanic membrane
- Pure tone audiometry screening: Pure tone audiometry screening was conducted using the Kuduwave Pro 5000 Portable Audiometey(HP laptop 15s-dy3xxx,11th

Gen Intel(R) Core ™) for pure tone audiometry screening. Thresholds were obtained using a modified version of the Hughson-Westlake procedure (Carhart & Jerger, 1959) for air conduction thresholds (250-4000 Hz). Bone conduction thresholds were not measured.

- Immittance evaluation: Immittance evaluation was carried out using the portable Titan Interacoustics handheld immittance meter. Immittance evaluation was performed using a 226 Hz probe tone at 85 dB SPL, and ipsilateral and contralateral acoustic reflexes were obtained using the same probe tone at octave frequencies from 250 to 4000 Hz. Individuals with tympanometric types other than A and its variants or with absent reflexes were excluded from the study.
- Otoacoustic emission screening: Otoacoustic emission screening was conducted using the Portable OAE screening instrument ERO SCAN Maico for DPOAE screening with the stimulus paradigm L1/L2 = 65/55 and F2:F1 ratio = 1.22. The testing was performed for F2 frequencies between 500 Hz to 4000 Hz. The participant was seated comfortably in a chair and was 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. DPOAE screening was carried out, and the results were recorded.

3.3.3 Measurement of listening effort and fatigue:

Listening effort was measured using a dual-task paradigm, and listening-related fatigue was measured using Vanderbilt Fatigue Scale-Adult version-40 items (VFS-A-40).

Listening effort: Listening effort experienced by the participants was studied using a single question as a subjective measure and 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: "Did you experience difficulty understanding speech in the presence of noise?" Their responses were recorded verbatim and later analysed.

***The dual-task paradigm**:* The dual-task paradigm involved a primary task and a secondary task. 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(R 2014a (8.3.0.532). Twenty-five sentences each were mixed with noise at -6dB, 0db SNR and 6dB SNRs, using 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 were 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.

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 Most Comfortable Level. The test material was presented to the participants and their responses were recorded using Psychopy (v.2023.1.2) which was installed on the laptop (Legion Y540 -15IRH-PG0). The participants were instructed to listen carefully and understand the sentences presented to them in noise. After 5 sentences were presented, constituting 1 block of stimulus, 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 using a mouse. After a familiarity run of 2 blocks of stimuli in quiet, the task was carried out at 3 different SNRs (-6, 0, and +6). Five blocks of sentences were presented at each SNR.

***Listening-related fatigue**:* Listening-related fatigue was assessed using the Vanderbilt Fatigue Scale-Adult version-40 items (VFS-A-40). It was administered to evaluate the fatigue experienced by the participants. The questionnaire was 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 Academy of Higher Education ;*, 2023). The questionnaire measured listening-related fatigue by understanding 'how often the participant felt or responded in a specific manner in a particular circumstance' through 40 questions.

The responses were obtained in 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 may even have avoided such situations. However, if they chose "Never/Almost Never" for the same question, it meant that they almost never or never experienced that described reaction.

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.

3.4 Test environment

Pure tone audiometry screening, immittance screening, and OAE screening were carried out in quiet rooms accessible to the study participants. The dual task paradigm was conducted in a quiet room through a personal computer, and auditory stimuli were presented through calibrated noise cancellation headphones. The preliminary interview and administration of the questionnaire were conducted in a quiet room with adequate light.

Table 3.1.

A summary of all the test/skills assessed, the protocol/material used, and the outcome measures of the study.

Test/Skill assessed	**Protocol/Material**	**Outcome measure**
The noise level measurement of the working environment of the participants was conducted.	Ambient noise levels were measured in Government Divisional Press in Saraswathipuram, Mysuru; The South India Paper Mills LTD. (SIPM) in Nanjangudu; and AIISH, Mysore Campus using a B and K 2270SLM.	Ambient noise levels in Leq during peak hours were used to select the participants.
Pure tone audiometry screening	Pure tone audiometric screening was done using the Kuduwave Portable Audiometer. The Modified Hughson-Westlake procedure, as outlined by Carhart and Jerger in 1959, was used to determine air conduction (AC) thresholds across the frequency range from 250 Hz to 4 kHz.	The 4 frequency PTA was used to ensure normal hearing sensitivity in the participants.

Immitance screening	Otoscopy was done before immittance audiometry. The portable screening immittance meter Titan Interacoustics was used for immittance testing, employing the standard protocol used in the Audiology clinic, AIISH.	The tympanometric type and presence or absence of reflex were used for the inclusion criteria.
OAEs screening	The Portable OAE screening instrument Maico were used for DPOAE screening with the following stimulus paradigm: L1/L2 = 65/55; F2:F1 ratio = 1.20; F2 frequencies between 500 Hz to 4000 Hz.	Presence of OAEs was used to compare the groups.
Participants' perception of their speech perception abilities in noise was assessed.	A single question was asked: "Did you experience difficulty understanding speech in the presence of noise?"	Their response was taken as a subjective measure of listening effort.
Listening effort	Dual task paradigm: Kannada sentences from the sentence lists developed by Geetha et al. (2014) were used for the primary and secondary tasks. Sentences were presented at -6, 0, and +6 dB SNRs at the participants' most comfortable level. The primary task was sentence recognition in the presence of noise. The participants were instructed to understand the sentences. The 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 indicated listening effort.

Listening related fatigue	Vanderbilt Fatigue Scale-Adult version-40 items. It has 4 sub-scales	Total score (0 to 160) and subscale (Emotional, Social, Cognitive and Physical) scores (0 to 40).

3.5 Data Analysis

Statistical package for social sciences (SPSS) IBM SPSS, Version 20.0 software. (IBM Corp., Armonk, N.Y., USA) software was used for statistical analysis. Shapiro Wilk's Test was performed to find the normal distribution of the data. The following statistical analysis were performed on the data.

1. Descriptive statistics were performed to examine the median, minimum, maximum, and inter quartile range of the Noise-unexposed group and Noise-Exposed Groups on the secondary task of the DTP at different SNRs and the scores of VFS-A-40 subscales and the total score VFS-A-40.
2. Mann-Whitney U test was administered to check whether there is any difference in Listening effort and fatigue in Noise-unexposed group and Noise-Exposed Groups
3. Spearman's rank correlation was administered to check the correlation between the DTP and VFS-A-40 Scores..

Chapter 4

Results

The primary objective of this study was to explore the differences in listening effort and fatigue between individuals exposed to noise levels below the Damage Risk Criteria (DRC) (the noise-exposed group) and those without such exposure (the noise-unexposed group). The research involved analysing the scores of the secondary task of listening effort and the Vanderbilt Fatigue Scale-Adult version (VFS-A) scores obtained from both the Noise-exposed group and Noise-unexposed group.

The study hypothesized that there is significant difference in the response parameters of Dual task paradigm (DTP) and Vanderbilt fatigue scale A-40 (VFS-A40) among the two groups of participants. All participants responded with no reported difficulty understanding speech in the presence of noise when asked the single question.("Did you experience difficulty understanding speech in the presence of noise?")

The data were statistically analysed for the influence of noise exposure below DRC on the participants, using SPSS software version 2.1 (IBM Corp., Armonk, N.Y., USA). The data were found to be non-normally distributed on Shapiro-Wilks test of normality ($p<0.05$). Therefore, all the between group comparisons were made using the Mann-Whitney U test and correlation analysis was done using Spearman's test of correlation. The results of various comparisons will be presented under the following headings:

4.1 Comparison of Secondary Task Scores of Listening Effort on Dual Task Paradigm Between Noise-unexposed group and Noise-Exposed Groups at Different SNRs.

4.2 Comparison of VFS-A Checklist Scores for Listening Fatigue Between Noise-unexposed group and Noise-Exposed Groups.

4.3 Correlation Between Scores of Secondary Task of Dual Task Paradigm and Total Scores of VFS-A Checklist.

4.1Comparison of Secondary Task Scores of Listening Effort Between Noise-unexposed group and Noise-Exposed Groups at Different SNRs

The Median, minimum, maximum, and inter quartile range of scores obtained by the Noise-unexposed group and Noise-Exposed Groups on the secondary task of the DTP at three different SNRs (-6, 0 and +6 dB) are shown in Figure 1. In general, the scores were lower for noise-exposed group than for Noise-unexposed group. The scores on dual task paradigm for +6dB SNR ranged from 19 to 25 for Noise-unexposed group and 11 to 22 for noise-exposed group; for 0dB SNR it ranged from 18 to 25 Noise-unexposed group and 13 to 23 for noise-exposed group; for -6dB SNR it ranged from 16 to 24 for Noise-unexposed group and 12 to 20 for noise-exposed group. The scores obtained for secondary task of the DTP by the participants in the Noise-unexposed group were higher than those of the noise-exposed group in the secondary task.

The scores obtained by the participants in the two groups were compared using the Mann-Whitney U test. The comparisons were made separately for -6, 0, and +6dB SNRs. The comparisons revealed significant difference between the two groups at all the SNRs the scores obtained at +6dB SNR (*Z*=-4.993, *p*=0.000),0dB SNR(*Z*=-4.998, *p*=0.000) and at -6dB SNR(*Z*=-4.484., *p*=0.000).

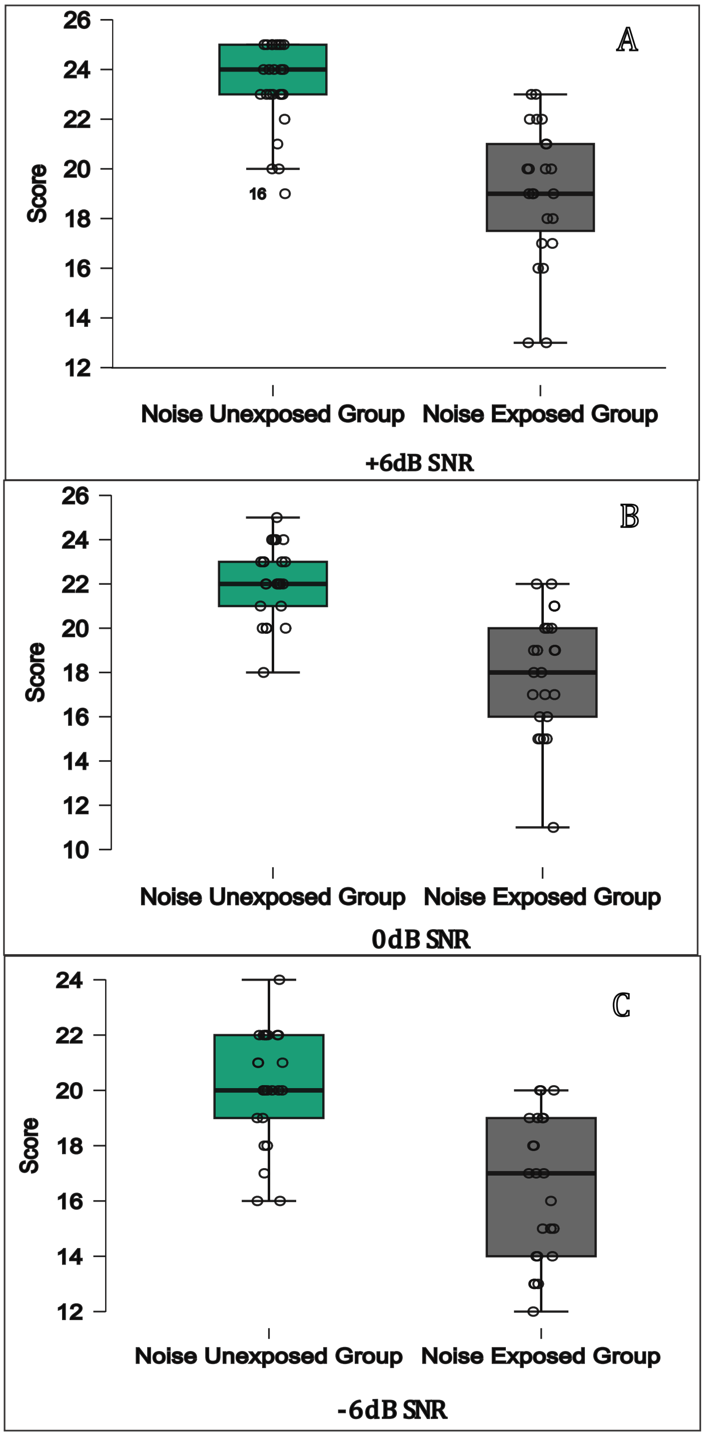


Figure 4.1: *The median, minimum, maximum, and inter quartile range of scores obtained by the Noise-unexposed group and Noise-Exposed Groups on the secondary task of the DTP at 6dB SNR (A), 0dB SNR (B), and -6 dB SNR (C).*

4.2 Comparison of VFS-A Checklist Scores for Listening Fatigue Between Noise-Unexposed Group and Noise-Exposed Groups:

The Median, minimum, maximum, and inter quartile range of scores obtained by the Noise-unexposed group and Noise-Exposed Groups on VFS-A40 checklist on its four different subscales [Emotional (E), Social (S), Cognitive (C) and Physical (P)] and total VFS-A40 are shown in Figure 4.2.

The VFS-A 40 scores for emotional domain ranged from 0 to 4 for Noise-unexposed group and 0 to 12 for noise-exposed group. The VFS-A 40 scores for Social domain ranged from 0 to 3 for Noise-unexposed group and 0 to 16 for noise-exposed group. The VFS-A 40 scores for Cognitive domain ranged from 0 to 4 for Noise-unexposed group and 0 to 13 for noise-exposed group. The VFS-A 40 scores for Physical domain ranged from 0 to 6 for Noise-unexposed group and 0 to 13 for noise-exposed group. In all the 4 domains and the total score were more for noise-exposed group than noise-unexposed group.

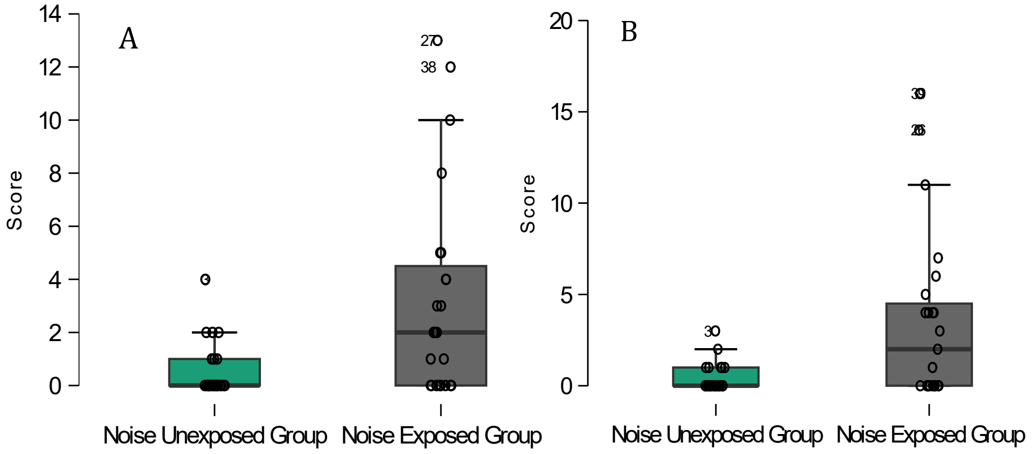
The scores were compared between the two groups separately for the four subscales and the total VFS-A40. The standard deviation was higher in the scores making it difficult to evaluate normality. So the Mann-Whitney test was employed for the comparison. The results of the Comparison are given in Table 4.1

Table 4.1: Results of Mann-Whitney U test for subscales scores and the overall score on the VFS A-40 questionnaire between noise-exposed group and noise unexposed group.

Variables	**Z**	**Sig**
VFSA-40Cognitive subscale	-4.242	.000
VFS A-40 Social subscale	-2.793	.005
VFS A-40 Emotional	-3.111	.002
VFS A-40 Physical	-3.724	.000
VFS TOTAL	-4.115	.000

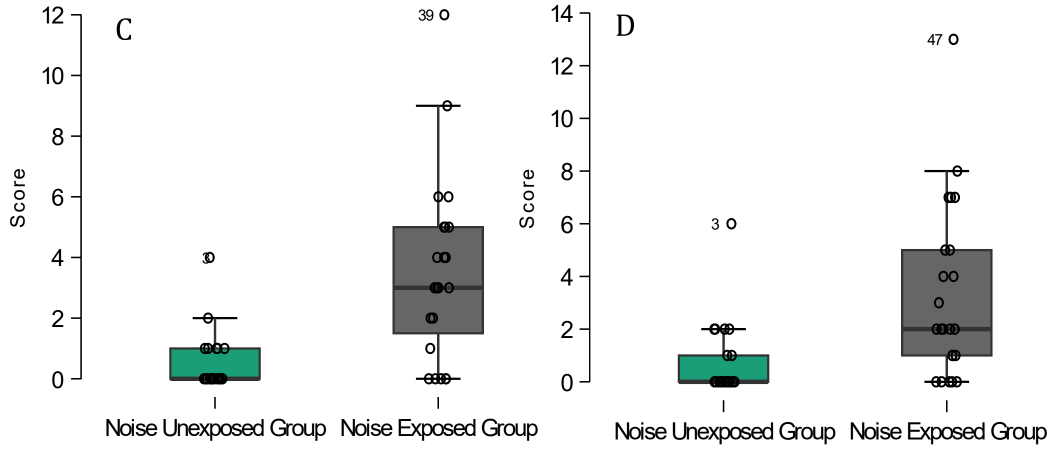
Table 4.1

The findings showed significant difference between the two groups in the scores obtained for the different subsections and the total VFS-A-40 score.



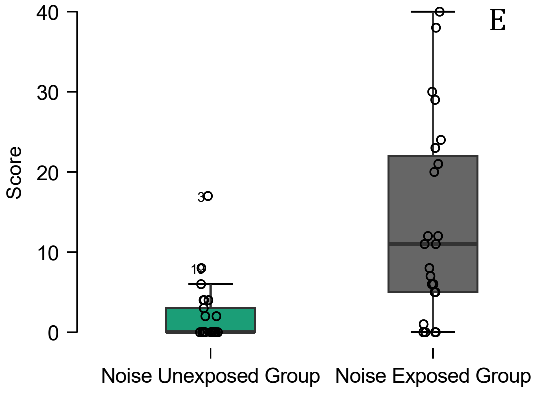
Emotional Subscale

Social Subscale



Cognitive Subscale

Physical Subscale



VFS-A-40 Total

Figure 4.2: The median, minimum, maximum, and inter quartile range of scores obtained by the Noise-unexposed group and Noise-Exposed Groups on the the VFS-A-40 Emotional Subscale (A), VFS-A-40 Social Subscale (B), VFS-A-40 Cognitive Subscale (C), VFS-A-40 Physical Subscale(D) and, VFS-A-40 Total Score(E)

4.3 Correlation Between Scores of Secondary Task of Dual Task Paradigm and Total Scores of VFS-A Checklist(within group)

Any correlation between the scores of the secondary task in the dual task paradigm (assessing listening effort) and the total scores obtained from the VFS-A checklist (evaluating listening fatigue) was examined using the Spearman rank correlation test. The results showed no significant correlation between the scores of listening effort and listening fatigue in the noise -Unexposed (Table 4.1) or the Noise-Exposed (Table 4.2) groups.

Noise-Unexposed Group Correlation

The table 4.2 Presents the Spearman's rank correlation coefficients between VFS-A and DPT of noise-unexposed group.

Variable	DTP 6dB SNR		DTP 0dB SNR		DTP -6dB SNR	
	Correlation coefficient	Significance	Correlation coefficient	Significance	Correlation coefficient	Significance
VFS-A-40 Cognitive Subscale	-.112	.592	-.145	.489	-.114	.587
VFS-A-40 Social Subscale	-.112	.592	-.145	.489	-.114	.587
VFS-A-40 Emotional Subscale	-.166	.428	-.185	.376	-.113	.592
VFS-A-40 Physical Subscale	-.045	.831	-.148	.479	.197*	.345
VFS-A-40 Total Score	-.098	.642	-.107	.612	.039	.855

Table 4.2

Noise-Exposed Group Correlation

The table 4.3 presents the Spearman's rank correlation coefficients between VFS-A and DTP of Noise -Exposed Group.

Variable	DTP 6dB SNR		DTP 0dB SNR		DTP -6dB SNR	
	Correlation coefficient	Sig.(2tailed)	Correlation coefficient	Sig.(2tailed)	Correlation coefficient	Sig.(2tailed)
VFS-A-40 Cognitive Subscale	0.082	.709	0.038	.864	-.020	.927
VFS-A-40 Social Subscale	0.256	.238	0.328	.127	0.223	.305
VFS-A-40 Emotional Subscale	.240	.270	0.260	.227	-0.051	.817
VFS-A-40 Physical Subscale	0.317	.141	0.271	.211	0.084	.703
VFS-A-40 Total Score	0.209	.338	0.259	.233	.0041	.851

Table 4.3

Chapter 5

Discussion

The aim of the study was to explore the differences in listening effort and fatigue between individuals exposed to noise levels below the Damage Risk Criteria (DRC) (the noise-exposed group) and those without such exposure (the noise-unexposed group). The performance in the secondary task (recall) of the dual task paradigm (DTP) was considered as a measure of listening effort, and scores on the Vanderbilt Fatigue Scale-Adult version- 40 items (VFS-A40) questionnaire was taken as a measure of listening-related fatigue. The findings in general showed that individuals in the noise-exposed groups experienced significantly higher effort and fatigue compared to individuals in the noise-unexposed group.

As was expected, when the Signal to Noise Ratios (SNRs) reduced (-6), the scores on last-word recall task in DTP reduced, indicating increased effort among the participants. This was true in both the groups. Though none of the participants indicated that they perceived increased effort while listening to speech in the presence of noise, their scores reduced on DTP, indicating increased listening effort. This may be because the increased effort was not perceived to affect their functionality on a daily basis. The difficulty noted during our tests should have been a rare occurrence, considering that on an everyday basis, For everyday conversations, such as face-to-face conversations or phone calls such poor signal-to-noise ratio (SNR) is not usually encountered.

It was seen that the noise-exposed group performed significantly poorer than the noise-unexposed group at all three SNRs studied. This means to say that exposure to noise for longer durations, even when the levels are below DRC, results in increased effort while listening to speech in noise. It should also be noted that this finding is from individuals with normal hearing sensitivity, with no complaints of difficulty while listening in noise.

The scores of the VFS-A 40 measured the listening-related fatigue in 4 domains [Emotional (E), Social (S), Cognitive (C) and Physical (P)]. The scores were more in noise exposed group than the noise unexposed group, indicating increased listening-related fatigue in individuals exposed to noise levels below the DRC also. The scores were not particularly more in any specific domain, indicating that all domains were affected by listening-related fatigue.

Speech perception is a multi-dimensional process that involves factors like linguistic knowledge, cognitive capacities like attention and memory, aside from the hearing sensitivity of an individual and the listening environment. Speech perception in degraded acoustic conditions like in the presence of noise lets us study the importance of cognitive capacities, and therefore is considered a measure of the listening effort. Increased listening effort in populations exposed to noise levels below DRC shows that noise-exposure to non-hazardous levels too can be detrimental to perception of speech. Listening-related fatigue among individuals exposed to noise levels below DRC shows that allocation of cognitive resources for listening tasks impacts an individual’s functioning in emotional, social, cognitive, and physical domains.

Increased listening effort and fatigue experienced by individuals in the noise-exposed groups may also be indicative of subtle changes to auditory processing which are important for speech perception in noise. As reported by Maruthy et al. (2018), shopkeepers exposed to environmental noise levels below the DRC had significantly poorer auditory stream segregation abilities and working memory capacities. The reason for increased listening effort and fatigue in the participants of the current study could be attributed to similar changes in their auditory processing and working memory capacities.However,a direct relationship cannot be drawn, since the auditory processing and working memory skills were not measured in the current study's participants. Nevertheless, influence of exposure to noise on the higher auditory functions could be a plausible explanation for the same. The current study adds on to the relevance of the findings of the study by (Maruthy et al., 2018), by showing the impact of the effects of exposure to noise below levels of DRC on higher auditory functions. The findings indicate that increased effort and listening fatigue are direct consequences of such exposure.

Kumar et al. (2012) has previously studied speech perception scores and temporal processing skills among individuals with normal hearing exposed to noise (train drivers exposed to occupational engine noise). The findings from their study revealed that, when exposed to noise, the train drivers exhibited notably lower speech recognition scores in comparison to a control group. They also observed a correlation between these reduced scores and their diminished temporal processing skills. However, in their study, individuals were exposed to noise levels above the DRC, while in the present study, the exposure levels were below the DRC. But, both the participants in the present study and the previous study had normal hearing. However, in order to establish clear associations between exposure to noise levels below DRC, speech perception in noise, working memory skills, temporal processing skills, and listening effort and fatigue, a study should explore all of these parameters in the same population.

Increased listening effort and fatigue in individuals with noise exposure may be related to Cochlear Synaptopathy, a condition that affects the synapses between hair cells in the cochlea and auditory nerve fibers. Several animal studies have shown that exposure to high-intensity noise can lead to cochlear synaptopathy, even if it doesn't result in permanent hearing threshold shifts (Kujawa & Liberman 2009; Furman, Kujawa, & Liberman 2013; Valero et al. 2017).

A recent systematic review of 25 studies conducted by DiNino et al., (2022) focused on adults with normal hearing thresholds (NHTs) or near-NHTs. The participants had varying degrees of cochlear synaptopathy, based on factors such as noise exposure history and age. Among the 47 experiments reviewed, 22 (46.8%) found a significant relationship between speech perception performance and one or more proxies of noise-induced cochlear synaptopathy.

Standard audiometric evaluations may not be sensitive enough to identify cochlear synaptopathy. Therefore, additional tests such as ultra-high-frequency audiometry, ABR wave I amplitude, summating potential-to-action potential ratio, and speech recognition in noise (with and without temporal distortion) may be necessary to identify auditory dysfunction in individuals with normal hearing (Barbee et al., 2018).

Evidence suggests that noise-induced hearing loss (NIHL) is associated with damage to the synapses between inner hair cells (IHCs) and type-I spiral ganglion neurons (SGNs). Noise exposure can harm both the presynaptic ribbons and postsynaptic nerve terminals of these ribbon synapses (Shi et al., 2016).

In the current study, all participants had normal hearing, as determined by standard audiometric evaluations. However, the study did not include additional tests like ultra-high-frequency audiometry, ABR wave I amplitude, summating potential-to-action potential ratio, which could provide further insights into the possibility of cochlear synaptopathy in individuals with normal hearing. This study sheds light on the potential presence of cochlear synaptopathy in individuals with hearing loss, emphasizing the importance of considering additional diagnostic tests beyond standard audiometry to fully understand auditory function in such cases.

Auditory effects of noise, including hearing loss may not be evident in these individuals. However, increased effort while listening to speech may later result in increased fatigue in these participants. This may in turn affect their quality of life. Based on the findings of the study, the null hypotheses that

- ‘there is no effect of noise exposure below DRC on listening effort’ is rejected.
- ‘there is no effect of noise exposure below DRC on listening-related fatigue’ is rejected.

Increased fatigue has been observed in individuals with noise exposure even when the exposure levels were below the DRC. Currently, there is a lack of research on listening fatigue in individuals with noise exposure. The present study aims to establish a foundation for the study of listening fatigue in individuals exposed to noise.

Chapter 6

Summary and Conclusion

Exposure to noise level above Damage risk criteria were proven to have both auditory and non auditory effects. However exposure to noise below DRC, thought considered safe for human listening, can cause sub clinical damage. Working memory and temporal processing skills are reported to be affected in exposure to noise below DRC Maruthy et al., (2018). The objectives of the study were to compare the listening effort between individuals with and without prolonged exposure to noise below DRC using a dual task paradigm and The listening-related fatigue between individuals with and without prolonged exposure to noise below DRC, using the Vanderbilt Fatigue Scale-Adult version-40 items (VFS-A-40) in Kannada.

In the dual task paradigm, target sentences were presented at each participant's Most Comfortable Level (MCL), which helped assess their listening effort at different SNRs. Additionally, the VFS-A-40 was utilized to measure listening fatigue. The results indicated significant main effects of both SNRs and groups on listening effort and fatigue. The group exposed to higher noise levels exhibited significantly higher listening effort in both primary and secondary listening tasks compared to the noise-unexposed group. Furthermore, as anticipated, listening effort increased as SNRs decreased.

Furthermore, the scores on the VFS-A-40 were also lower in the noise-exposed group compared to the control group. However, there was no significant correlation observed between listening effort and listening fatigue within either group. Notably, the noise-exposed group demonstrated more effortful listening than the control group at lower SNRs.

Implication of the Study

The study has revealed even in individuals with normal hearing who have been exposed to noise levels below the Damage Risk Criteria (DRC),showed increased listening effort and fatigue. This highlights the necessity of including listening effort and listening-related fatigue assessments in audiological test batteries.

Reference

Alhanbali, S., Dawes, P., Lloyd, S., & Munro, K. J. (2017). Self-Reported Listening-Related Effort and Fatigue in Hearing-Impaired Adults. *Ear & Hearing*, *38*(1), e39–e48. https://doi.org/10.1097/AUD.0000000000000361

Anderson Gosselin, P., & Gagné, J.-P. (2011). Older Adults Expend More Listening Effort Than Young Adults Recognizing Speech in Noise. *Journal of Speech, Language, and Hearing Research*, *54*(3), 944–958. https://doi.org/10.1044/1092-4388(2010/10-0069)

Barbee, C., James, J., Park, J., Smith, E., Johnson, C., Clifton, S., & Danhauer, J. (2018). Effectiveness of Auditory Measures for Detecting Hidden Hearing Loss and/or Cochlear Synaptopathy: A Systematic Review. *Seminars in Hearing*, *39*(02), 172–209. https://doi.org/10.1055/s-0038-1641743

Basner, M., Babisch, W., Davis, A., Brink, M., Clark, C., Janssen, S., & Stansfeld, S. (2014). Auditory and non-auditory effects of noise on health. *The Lancet*, *383*(9925), 1325–1332. https://doi.org/10.1016/S0140-6736(13)61613-X

Bernarding, C., Strauss, D. J., Hannemann, R., & Corona-Strauss, F. I. (2012). Quantification of listening effort correlates in the oscillatory EEG activity: A feasibility study. *2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, 4615–4618. https://doi.org/10.1109/EMBC.2012.6346995

Bressler, S., Goldberg, H., & Shinn-Cunningham, B. (2017). Sensory coding and cognitive processing of sound in Veterans with blast exposure. *Hearing Research*, *349*, 98–110. https://doi.org/10.1016/j.heares.2016.10.018

C. Kohrman, D., Wan, G., Cassinotti, L., & Corfas, G. (2020). Hidden Hearing Loss: A Disorder with Multiple Etiologies and Mechanisms. *Cold Spring Harbor Perspectives in Medicine*, *10*(1), a035493. https://doi.org/10.1101/cshperspect.a035493

Colby, S., & McMurray, B. (2021). Cognitive and Physiological Measures of Listening Effort During Degraded Speech Perception: Relating Dual-Task and Pupillometry Paradigms. *Journal of Speech, Language, and Hearing Research*, *64*(9), 3627–3652. https://doi.org/10.1044/2021_JSLHR-20-00583

Davis, H., Schlundt, D., Bonnet, K., Camarata, S., Bess, F. H., & Hornsby, B. (2021). Understanding Listening-Related Fatigue: Perspectives of Adults with Hearing Loss. *International Journal of Audiology*, *60*(6), 458–468. https://doi.org/10.1080/14992027.2020.1834631

Desjardins, J. L., & Doherty, K. A. (2014). The Effect of Hearing Aid Noise Reduction on Listening Effort in Hearing-Impaired Adults. *Ear & Hearing*, *35*(6), 600–610. https://doi.org/10.1097/AUD.0000000000000028

DiNino, M., Holt, L. L., & Shinn-Cunningham, B. G. (2022). Cutting Through the Noise: Noise-Induced Cochlear Synaptopathy and Individual Differences in Speech Understanding Among Listeners With Normal Audiograms. *Ear & Hearing*, *43*(1), 9–22. https://doi.org/10.1097/AUD.0000000000001147

Downs, D. W. (1982). Effects of Hearing Aid Use on Speech Discrimination and Listening Effort. *Journal of Speech and Hearing Disorders*, *47*(2), 189–193. https://doi.org/10.1044/jshd.4702.189

Dudek, B., Marszał-Wiśniewska, M., Merecz-Kot, D., Sułkowski, W., & Bortkiewicz, A. (1991). Effects of noise on cognitive processes of individuals in a laboratory experiment. *Polish Journal of Occupational Medicine and Environmental Health*, *4*(3), 269–279. http://www.ncbi.nlm.nih.gov/pubmed/1819345

Dwyer, R. T., Gifford, R. H., Bess, F. H., Dorman, M., Spahr, A., & Hornsby, B. W. Y. (2019). Diurnal Cortisol Levels and Subjective Ratings of Effort and Fatigue in Adult Cochlear Implant Users: A Pilot Study. *American Journal of Audiology*, *28*(3), 686–696. https://doi.org/10.1044/2019_AJA-19-0009

Degeest, S., Kestens, K., & Keppler, H. (2022). Listening Effort Measured Using a Dual-task Paradigm in Adults With Different Amounts of Noise Exposure. *Ear & Hearing*, *43*(3), 899–912. https://doi.org/10.1097/AUD.0000000000001138

Finitzo-Hieber, T., & Tillman, T. W. (1978). Room Acoustics Effects on Monosyllabic Word Discrimination Ability for Normal and Hearing-Impaired Children. *Journal of Speech and Hearing Research*, *21*(3), 440–458. https://doi.org/10.1044/jshr.2103.440

Geetha, C., Kumar, K. S. S., Manjula, P., & Pavan, M. (2014). Development and standardisation of the sentence identification test in the Kannada language. *Journal of Hearing Science*, *4*(1), 18–26. https://www.journalofhearingscience.com/Development-and-standardisation-of-the-sentence-nidentification-test-in-the-Kannada,120592,0,2.html

Hicks, C. B., & Tharpe, A. M. (2002). Listening Effort and Fatigue in School-Age Children With and Without Hearing Loss. *Journal of Speech, Language, and Hearing Research*, *45*(3), 573–584. https://doi.org/10.1044/1092-4388(2002/046)

Hornsby, B. W. Y., Davis, H., & Bess, F. H. (2021). The Impact and Management of Listening-Related Fatigue in Children with Hearing Loss. *Otolaryngologic Clinics of North America*, *54*(6), 1231–1239. https://doi.org/10.1016/j.otc.2021.07.001

Huang, L., Zhang, Y., Wang, Y., & Lan, Y. (2021). Relationship between Chronic Noise Exposure, Cognitive Impairment, and Degenerative Dementia: Update on the Experimental and Epidemiological Evidence and Prospects for Further Research. In *Journal of Alzheimer's Disease* (Vol. 79, Issue 4, pp. 1409–1427). IOS Press BV. https://doi.org/10.3233/JAD-201037

Irgens-Hansen, K., Gundersen, H., Sunde, E., Baste, V., Harris, A., Bråtveit, M., & Moen, B. (2015). Noise exposure and cognitive performance: A study on personnel on board Royal Norwegian Navy vessels. *Noise and Health*, *17*(78), 320. https://doi.org/10.4103/1463-1741.165057

Kumar, U. A., Ameenudin, S., & Sangamanatha, A. V. (2012). Temporal and speech processing skills in normal hearing individuals exposed to occupational noise. *Noise & Health*, *14*(58), 100–105. https://doi.org/10.4103/1463-1741.97252

Lin, H. W., Furman, A. C., Kujawa, S. G., & Liberman, M. C. (2011). Primary Neural Degeneration in the Guinea Pig Cochlea After Reversible Noise-Induced Threshold Shift. *Journal of the Association for Research in Otolaryngology*, *12*(5), 605–616. https://doi.org/10.1007/s10162-011-0277-0

Lobarinas, E., Spankovich, C., & Le Prell, C. G. (2017). Evidence of "hidden hearing loss" following noise exposures that produce robust TTS and ABR wave-I amplitude reductions. *Hearing Research*, *349*, 155–163. https://doi.org/10.1016/j.heares.2016.12.009

Maruthy, S., Gnanateja, Gn., Chengappa, P., Publius, S., & Athreya, V. (2018). Effect of below-damage-risk criteria environmental noise on auditory perception and working memory. *Indian Journal of Otology*, *24*(2), 98. https://doi.org/10.4103/indianjotol.INDIANJOTOL_25_18

McGarrigle, R., Munro, K. J., Dawes, P., Stewart, A. J., Moore, D. R., Barry, J. G., & Amitay, S. (2014). Listening effort and fatigue: What exactly are we measuring? A British Society of Audiology Cognition in Hearing Special Interest Group 'white paper.' *International Journal of Audiology*, *53*(7), 433–445. https://doi.org/10.3109/14992027.2014.890296

Nabelek, A. K., & Pickett, J. M. (1974). Monaural and Binaural Speech Perception through Hearing Aids under Noise and Reverberation with Normal and Hearing-Impaired Listeners. *Journal of Speech and Hearing Research*, *17*(4), 724–739. https://doi.org/10.1044/jshr.1704.724

Noreña, A. J., Gourévitch, B., Aizawa, N., & Eggermont, J. J. (2006). Spectrally enhanced acoustic environment disrupts frequency representation in cat auditory cortex. *Nature Neuroscience*, *9*(7), 932–939. https://doi.org/10.1038/nn1720

Ohlenforst, B., Zekveld, A. A., Jansma, E. P., Wang, Y., Naylor, G., Lorens, A., Lunner, T., & Kramer, S. E. (2017). Effects of Hearing Impairment and Hearing Aid Amplification on Listening Effort. *Ear and Hearing*, *38*(3), 267–281. https://doi.org/10.1097/AUD.0000000000000396

Pichora-fuller, M. K., Kramer, S. E., Eckert, M. A., Edwards, B., Hornsby, B. W. Y., Humes, L. E., Lemke, U., Lunner, T., Matthen, M., Mackersie, C. L., Naylor, G., Phillips, N. A., Richter, M., Rudner, M., Sommers, M. S., Tremblay, K. L., &

Wingfield, A. (2016). *Hearing Impairment and Cognitive Energy : The Framework for Understanding Effortful Listening (FUEL).*

Picou, E. M., & Ricketts, T. A. (2014). The Effect of Changing the Secondary Task in Dual-Task Paradigms for Measuring Listening Effort. *Ear & Hearing*, *35*(6), 611–622. https://doi.org/10.1097/AUD.0000000000000055

Park, J. H., & Viirre, E. (2010). Vestibular migraine may be an important cause of dizziness/vertigo in perimenopausal period. *Medical Hypotheses*, *75*(5), 409–414. https://doi.org/10.1016/j.mehy.2009.04.054

Rönnberg, N., Rudner, M., Lunner, T., & Stenfelt, S. (2014). Assessing listening effort by measuring short-term memory storage and processing of speech in noise. *Speech, Language and Hearing*, *17*(3), 123–132. https://doi.org/10.1179/2050572813Y.0000000033

Sarampalis, A., Kalluri, S., Edwards, B., & Hafter, E. (2009). Objective Measures of Listening Effort: Effects of Background Noise and Noise Reduction. *Journal of Speech, Language, and Hearing Research*, *52*(5), 1230–1240. https://doi.org/10.1044/1092-4388(2009/08-0111)

Seeber, K. G. (2013). Cognitive load in simultaneous interpreting. *Target. International Journal of Translation Studies*, *25*(1), 18–32. https://doi.org/10.1075/target.25.1.03see

Shetty, H. N., Raju, S., Kumar, Y., & Singh, S. S. (2022). Listening effort in individuals with noise-induced hearing loss. *Hearing, Balance and Communication*, *20*(4), 263–271. https://doi.org/10.1080/21695717.2022.2102733

Thompson, R., Smith, R. B., Bou Karim, Y., Shen, C., Drummond, K., Teng, C., & Toledano, M. B. (2022). Noise pollution and human cognition: An updated systematic review and meta-analysis of recent evidence. *Environment International*, *158*, 106905. https://doi.org/10.1016/j.envint.2021.106905

Wieczerzak, K. B., Patel, S. V., MacNeil, H., Scott, K. E., Schormans, A. L., Hayes, S. H., Herrmann, B., & Allman, B. L. (2021). Differential Plasticity in Auditory and Prefrontal Cortices, and Cognitive-Behavioral Deficits Following Noise-Induced Hearing Loss. *Neuroscience*, *455*(November), 1–18. https://doi.org/10.1016/j.neuroscience.2020.11.019

Zekveld, A. A., Kramer, S. E., & Festen, J. M. (2010). Pupil Response as an Indication of Effortful Listening: The Influence of Sentence Intelligibility. *Ear & Hearing*, *31*(4), 480–490. https://doi.org/10.1097/AUD.0b013e3181d4f251