SUPPRESSION EFFECT OF CONTRALATERAL MOBILE APPLICATION-BASED SOUND THERAPY AMONG ADULTS WITH AND WITHOUT TINNITUS

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by

KAMALIN MASTURA BINTI MOHD YAHYA

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for the degree of Bachelor of Health Sciences (Honours) Audiology

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CERTIFICATION

This is to certify that the dissertation entitled 'Suppression Effect of Contralateral Mobile-Application Based Sound Therapy among Adults with and without Tinnitus' is the project done by KAMALIN MASTURA BINTI MOHD YAHYA from September 2024 to July 2025 under my supervision. We have read this dissertation and, in our opinion, it fulfils the acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation to be submitted in partial fulfilment for the degree of Bachelor of Health Sciences (Honours)(Audiology). Research work and collection of data belong to the Universiti Sains Malaysia.

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DECLARATION

I hereby declare that the work has been done by myself, all the results are of my own investigation and any ideas or quotation from others' work are fully acknowledged according to the standard referring practices of the discipline. I also declare that it has not been submitted as a whole in previous or concurrently for any other degress in any institutions. I acknowledge that that the research work and collection of data belong to Universiti Sains Malaysia.

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LIST OF ABBREVIATIONS AND SYMBOLS

PTA	Pure Tone Audiometry
DPOAE	Distortion Products of Otoacoustic Emission
NRS	Numeric Rating Scale
WN	White Noise
RS	Rain Sound
dB HL	Decibels Hearing Level
DP	Distortion Products
Hz	Hertz
USM	University Sains Malaysia
≤	Equal and less than
<	More than
HL	Hearing Level
Freq	Frequency
SD	Standard Deviation
IQR	Interquartile Range
JASP	Jeffrey's Amazing Statistics Program

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KESAN PENEKANAN TERHADAP TERAPI BUNYI BERASASKAN APLIKASI MUDAH ALIH KONTRALATERAL DALAM KALANGAN ORANG DEWASA DENGAN DAN TANPA TINNITUS.

ABSTRAK

Tinnitus ialah persepsi bunyi tanpa rangsangan pendengaran luaran. Terapi bunyi, terutamanya apabila dihantar melalui aplikasi mudah alih, telah menjadi satu bentuk terapi yang mudah didapati untuk mengurangkan gejala tinnitus. Tujuan kajian ini adalah untuk meneroka kesan penekanan terapi bunyi berasaskan aplikasi mudah alih secara kontralateral dalam kalangan orang dewasa yang mengalami tinnitus. Kajian intervensi ini melibatkan 33 orang dewasa (61 telinga), iaitu 18 peserta (31 telinga) dengan tinnitus dan 15 peserta (30 telinga) tanpa tinnitus. Peserta berumur antara 20 hingga 40 tahun (purata umur = 23 ± 1.037 tahun) bagi kumpulan tinnitus dan (purata umur = 23 ± 1.952 tahun) bagi kumpulan tanpa tinnitus, kesemuanya mempunyai fungsi telinga tengah yang normal dan tiada patologi retrokoklea. Dalam kalangan peserta tinnitus, 16 peratus mempunyai pendengaran tahap ringan dan 84 peratus mempunyai pendengaran normal. Bagi kumpulan tanpa tinnitus, 7 peratus mempunyai pendengaran tahap ringan manakala 93 peratus mempunyai pendengaran normal. Sebanyak 26 telinga menunjukkan padanan frekuensi tinnitus (pitch matching) pada frekuensi tinggi (2kHz – 12.5kHz). Dua jenis terapi bunyi, iaitu bunyi putih (white noise) dan bunyi hujan dimainkan selama tiga minit melalui aplikasi mudah alih Resound Relief GN ke telinga kontralateral. Kesan penekanan dinilai menggunakan Distortion Product Otoacoustic Emissions (DPOAE) bermula dari 1.5kHz hingga 12kHz untuk kedua-dua kumpulan, manakala skala penilaian angka (numeric rating scale) dinilai hanya dalam kumpulan tinnitus. Peserta tinnitus diminta memilih jenis

bunyi yang mereka sukai dalam mengurangkan tinnitus. Sebanyak 71 peratus peserta lebih menyukai bunyi hujan manakala 29 peratus memilih bunyi putih. Pilihan ini selari dengan keputusan DPOAE yang menunjukkan pengurangan amplitud yang signifikan pada frekuensi padanan tinnitus menggunakan bunyi hujan ($p<0.05$) dengan saiz kesan 0.461. Sementara itu, bunyi putih tidak menunjukkan kesan yang signifikan ($p>0.05$; saiz kesan = 0.379). Apabila dianalisis pada semua frekuensi, kumpulan kawalan menunjukkan peningkatan amplitud yang signifikan pada 7kHz untuk bunyi putih dan pada 3kHz, 6kHz serta 12kHz untuk bunyi hujan. Walau bagaimanapun, dalam kalangan peserta tinnitus, hanya frekuensi 2kHz menunjukkan kesan penekanan menggunakan bunyi putih dan tiada kesan penekanan menggunakan bunyi hujan. Kedua-dua rangsangan bunyi menunjukkan kesan penekanan tinnitus yang signifikan pada skala penilaian angka ($p\leq0.05$). Bunyi hujan kontralateral lebih berkesan pada kawasan frekuensi padanan tinnitus, yang sejajar dengan pilihan terapi bunyi dalam kalangan peserta tinnitus. Penemuan ini menyokong potensi terapi bunyi berasaskan aplikasi mudah alih dalam pengurusan tinnitus, dengan bunyi hujan didapati lebih berkesan dalam menekan tinnitus dalam kalangan orang dewasa. Kajian berskala besar disarankan bagi menyokong penemuan kajian ini.

SUPPRESSION EFFECT OF CONTRALATERAL MOBILE APPLICATION-BASED SOUND THERAPY AMONG ADULTS WITH TINNITUS AND WITHOUT TINNITUS

ABSTRACT

Tinnitus is the perception of sound without an external auditory stimulus. Sound therapy, particularly when delivered through a mobile application, has become a readily available therapy for reducing tinnitus. This study aims to explore the suppression effect of contralateral mobile application-based sound therapy among adults with tinnitus. This intervention study involves 33 adults (61 ears), respectively 18 participants (31 ears) with tinnitus and 15 participants (30 ears) without tinnitus. Participants aged 20 to 40 years (mean = 23 ± 1.037 years) for the tinnitus group and (mean 23 $\pm$ 1.952) for the non-tinnitus group, having normal middle ear function and no retrocochlear pathology. Among them, 16 percent had mild hearing loss, and 84 percent had normal hearing in the tinnitus participants. 7 percent had mild hearing loss, and 93 percent had normal hearing in non-tinnitus participants. 26 ears demonstrated pitch matching at high frequencies (2kHz – 12.5kHz). Two types of sound therapy, namely white noise and rain sounds, were administered for three minutes using the Resound Relief GN mobile application to the contralateral ear. Suppression effects were assessed with distortion product otoacoustic emissions (DPOAEs) starting from 1.5kHz until 12kHz for both groups, and a numeric rating scale was assessed only in the tinnitus group. Tinnitus participants were also asked to choose a sound preference for reducing tinnitus. 71 percent of participants preferred rain sound, whereas 29 percent preferred white noise. This preference aligns with DPOAE results, which showed a significant result of amplitude reduction at the tinnitus pitch-matched frequency using rain sound ($p<0.05$) with an effect size of 0.461; meanwhile, white noise did not show a significant effect ($p>0.05$; effect size = 0.379). When analyzed at all frequencies, in control groups, the significant enhancement was shown at 7kHz for white noise

and 3kHz, 6kHz, and 12kHz for rain sound. However, in tinnitus participants, only 2kHz is found to have a suppression effect using white noise and no suppression effect using rain sound. Both stimuli showed significant tinnitus suppression effects on the numeric rating scale ($p<0.05$). Contralateral rain sound is more effective at pitch-matched areas, which align with the sound therapy preferences among tinnitus participants. These findings support the potential of mobile-based sound therapy in tinnitus management, with rain sound being more effective on tinnitus suppression among adults with tinnitus, and further large-scale studies are encouraged to support the findings of this study.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Tinnitus comes from the Latin word which is *tinnire,* which means ‘to ring’. It is a ringing or buzzing without the presence of an external stimulus. Tinnitus is a symptom of an underlying disease; however, it is not a disease. Most of the cases are idiopathic and primarily associated with sensorineural hearing loss. The perception of tinnitus differs between patients with tinnitus, such as the sound, frequency, and loudness. Some patients experience tinnitus in the form of high-frequency sound, cricket-like sound, environmental sound, etc.

At the fundamental level, tinnitus is divided into subjective and objective tinnitus. Subjective tinnitus can only be heard by a person with tinnitus; meanwhile, an objective tinnitus can also be heard by the examiner, such as a healthcare provider that are examining the patient. (Henry, 2016). The most common causes of tinnitus are noise exposure, aging, medications, and head injury, and in some cases, the cause is unknown. Tinnitus is also classified as sensory or neural, or middle ear.

Based on Jin et al. (2022) In the adult population worldwide, the prevalence of tinnitus is reported to be 10 percent to 15 percent. 20 percent of the individuals with tinnitus reported annoyance. Tinnitus can cause adverse effects on quality of life, such as anxiety, depression, insomnia, and post-traumatic stress disorder (PTSD). The higher in severity of tinnitus is said to be linked to diagnosis with psychological conditions, and there is a positive correlation between the severity of tinnitus and an increase in anxiety, insomnia, and depression. (Patil et al., 2023).

One of the methods to reduce the effects of tinnitus is by using sound therapy. Sound therapy is designed mainly based on tinnitus suppression principles or masking. Sound therapy is one of the effective management approaches, according to Reavis et al. (2012) Sound therapy has a 90 percent success rate when one of the 17 stimuli is administered to 20 chronic tinnitus sufferers. Based on Lee et al. (2023)where 14 studies were published from January 2018 until March 2023, where the main treatment that is being used in the studies is sound therapy, with 6 of the studies using basic sound therapy, followed by tinnitus rehabilitation therapy (TRT), combining sound therapy with counselling, which is 5 studies. 2 of them using notched sounds, one study each of acoustic coordination, rest neuromodulation, and binaural beats. The final findings are being concluded, where the sound therapy is being found to have a significant improvement for patients with tinnitus. Another research done by (Jin et al., 2021) where they administer sound therapy for 12 months towards two chronic tinnitus groups using different types of noise, with 14 participants in the study using broadband noise and 16 participants using notched noise. There is an improvement in the tinnitus among participants after the administration of sound therapy.

In the context of sound therapy, various stimuli are being used in different studies, such as unmodulated stimuli (white noise, narrowband noise), amplitude modulated stimuli, frequency modulated stimuli, natural sounds, etc. The usage of different stimuli is to investigate which stimulus is known best to suppress tinnitus among patients with tinnitus. One of the methods to gain access to stimulus is by using mobile applications that are specified for tinnitus patients. The sound that is available in the mobile application can ease the use of the sound therapy, as it can be easily accessed through a mobile phone and can be used remotely.

Mobile applications are defined as software applications that are developed for use on small, wireless computing devices such as tablets and smartphones. (Weichbroth, 2020). Based on the study conducted by Mehdi et al. (2020) In recent years, there has been an increase in interest in the development of smartphone apps that aim to help patients manage and treatment for their tinnitus. Currently, there are roughly 250 smartphone applications that are offering tinnitus-related therapies.

1.2 Problem statement & Study rationale

Tinnitus is one of the most common health symptoms that is being faced globally among adults, which affecting quality of life. Tinnitus is not only caused by presbycusis, but it is also caused by noise-induced hearing loss. Nowadays, it is becoming more common among younger people who have tinnitus due to noise-induced hearing loss. Sound therapy is one of the treatment options available for treating patients with tinnitus. In recent years, sound therapy has been integrated into mobile applications for ease of use. There are various sound therapies in free mobile applications that offer different types of sounds, and the selection of good mobile applications is crucial to ensure a good outcome in suppressing tinnitus. This application cannot only be used by the younger generation, but the older generation can also use this mobile application. Based on Siddharta (2024), by 2025, the number of smartphone users is estimated to grow by more than 30 million people, with domination from Millennials and Gen Z users. The elderly population has around 80 percent smartphone ownership. According to Mehdi et al. (2020), around 311 tinnitus mobile applications are available and the findings, only 7 applications have evidence based. Mobile applications have many different types of sounds, and different people have different sound preferences. Different types of sound have different effects on

tinnitus suppression, which can cause confusion about the type of sound that needs to be chosen to reduce tinnitus. Different sounds represent different categories, such as therapeutic sounds and nature sounds. In the therapeutic category, it consists of white noise, pink noise, etc. For the nature sound category, it consists of rain sounds, ocean waves, cicadas, etc. Based on Mondelli et al. (2020), white noise is proven to have the most suppressive effect towards reducing the tinnitus perception compared to narrowband noise and pink noise. Natural sound which is rain sound ranked as the first sound that has the most tinnitus suppression and preferred sound (Durai & Searchfield, 2017). Hence, indicating the reason for choosing white noise and rain sound in this study. The effect of the preferred sounds on suppressing the tinnitus needs to be investigated to ensure a good outcome from using sound therapy in mobile applications. Thus, this study will give an insight into which types of sound are the best in treating patients with tinnitus and which types of sound are the patients' preferences, that are conducted in the audiology USM clinic located in Malaysia.

1.3 Benefits of the Study

This study will benefit tinnitus patients with unilateral profound hearing loss and unilateral tinnitus patients. Patients who are experiencing tinnitus in the ear with profound hearing loss will have difficulty using sound therapy on the tinnitus ear, as the masking ability is limited when using sound therapy. Sound therapy generally will be used with MP3 players, hearing aids, and mobile applications. The sound therapy will need to be played at a high volume to make it audible. However, for tinnitus patients experiencing unilateral profound hearing loss, introducing the sound therapy to the tinnitus ear with profound hearing loss makes it impractical. Therefore,

contralateral sound therapy may be beneficial as sound therapy will be introduced to the better ear.

1.4 Research Questions

1. What are the sound therapy preferences for tinnitus suppression among adults with tinnitus?
2. What is the comparison of the suppression effects between different types of sound therapies in adults without tinnitus (control group)?
3. What is the comparison of the suppression effects between different types of sound therapies in adults with tinnitus?

1.5 Hypothesis

1.5.1 Null Hypothesis

1. There is no significant effect of the suppression effects between different types of sound therapies in adults without tinnitus (control group).

2. There is no significant effect of the suppression effects of different types of sound therapies in adults with tinnitus.

1.5.2 Alternative Hypothesis

1. There is a significant effect of the suppression effects between different types of sound therapies in adults without tinnitus (control group).

2. There is a significant effect of the suppression effects of different types of sound therapies in adults with tinnitus.

1.6 Objective

1.6.1 General Objective:

To determine the amount of suppression effect of contralateral mobile application-based sound therapy among adults with tinnitus.

1.6.2 Specific Objective:

1. To determine the sound therapy preferences for tinnitus suppression among adults with tinnitus.
2. To compare the suppression effects between different types of sound therapies in adults without tinnitus (control group).
3. To compare the suppression effects between different types of sound therapies in adults with tinnitus.

CHAPTER 2

LITERATURE REVIEW

2.1 Nature of tinnitus

2.1.1 Type of tinnitus

Tinnitus is known as the perception of a sound without an external auditory stimulus. Tinnitus can be categorized into two broad categories which is subjective and objective. Subjective tinnitus is only audible to the affected individual and not associated with any physical noise meanwhile, objective tinnitus is a sound that is generated in the body and reaches the ear via the conduction in body tissues (Chan, 2009).

2.1.1.1 Objective Tinnitus

Objective tinnitus is also known as somatic tinnitus. It is a type of rare tinnitus that is caused by mechanical sound that is present in the body. It is often generated by the vascular structure or muscular structure in the head and neck area. It further can be generated into three different groups which are pulsatile, mechanical and spontaneous. Pulsatile tinnitus originates from vascular etiologies may be due to the result of turbulence in the blood flow. The turbulent is originated by stenosis of the vessel lumen or an increase in blood flow volume. The turbulent flow will produce sound and will be transmitted directly to the inner ear. For the vessel of origin, it can either be arterial or venous. (Liyanage et al., 2006)

2.1.1.2 Subjective Tinnitus

Subjective tinnitus may be primary, and it may or may not be related to sensorineural hearing loss, or it may be secondary to various conditions like auditory nerve disease, conductive hearing loss, or others. It is an electrochemical phenomenon and not audible to the external listener. The site or origin of tinnitus most likely will be different for each patient, and to specifically identify the sites requires an intense research effort. Subjective tinnitus is said to be more common compared to objective tinnitus, where around 90 percent of patients have subjective tinnitus. Subjective tinnitus is rarely treated by surgical intervention. (Hertzano et al., 2016).

2.1.2 Association between Tinnitus and Hearing Loss

The risk factor for tinnitus is hearing loss. Tinnitus patients who have normal audiograms might have hearing loss above 8 kHz, which is not detected by clinical audiometry. The frequency range of hearing loss and tinnitus sensation is related. When the tinnitus pitch of the tinnitus patient matches a pure tone, most of the matches are at frequencies at which the hearing is impaired (König et al., 2006). Globally, about 10 percent to 15 percent of the general population is expected to be affected by tinnitus with or without hearing impairment. The prevalence of tinnitus is highly associated with the severity and frequency characteristics of hearing loss. (Manche et al., 2016).

There is a study where the sample of patients with noise-induced hearing loss where the patients consisted of 30 patients without tinnitus, 24 patients that have tone-like tinnitus, and 17 patients who had noise-like tinnitus. The patients generally had moderate to severe high-frequency hearing loss, where only some of the patients had moderate hearing loss in the low frequency's region. The findings from this study,

when the patients had tone-like tinnitus were asked about the dominant pitch of their tinnitus sensation, to pure tones (125, 250, 500, 750, 1, 2, 3, 4, 6, or 8 kHz). The tinnitus pitch generally matches frequencies where the hearing is impaired. The patient with tinnitus pitch $\leq$ 3kHz had the lowest audiogram pitch frequency and worst hearing, whereas the patient with tinnitus of $\geq$ 6kHz had the best hearing and highest audiogram edge frequency, and 4 kHz is intermediate. These relations suggest that the tinnitus pitch, the amount of hearing loss, and frequency range suggest that the occurrence of tinnitus depends on the severity of the hearing Impairment (König et al., 2006).

2.1.3 Localization of Tinnitus Perception

The location of tinnitus perception differs for each tinnitus patient. Survey and clinical databases indicate that tinnitus can be heard in the ears, head, and a combination of places. Most tinnitus sufferers have tinnitus localized to both ears, but when the tinnitus is heard on one ear, the tinnitus is mostly heard on the left ear. (Searchfield et al., 2024). Left-sided tinnitus is reported more frequently in subjects who are exposed to impulsive noise, and people with bilateral tinnitus report hearing sounds from the worst ear only. (Hallberg & Erlandsson, 1993).

2.1.4 Pathophysiology of Tinnitus

2.1.4.1 Peripheral or Cochlear Tinnitus

This cochlear-type tinnitus is defined as a tinnitus subtype that results from an aberrant activity that is generated at the periphery of the auditory system, which is before or at the cochlear level. The activity is increased in the cochlear nerve and continues up until the auditory cortex. The first mechanisms that result in tinnitus-

related activity in the cochlear nerve is the modulation of the endocochlear potential. (Noreña, 2015).

Cochlear spontaneous activity is strongly linked with endocochlear potential (EP). The outer hair cells also play a role in EP regulation by allowing current shunt through mechano-electric transduction (MET) channels. By limiting current shut, the EP can be raised by a reduction in the opening probability of MET channels. The MET channels' opening probability depends on stereocilium bundle deflection. Any shift of MET channels toward the scala tympani can raise the EP. Intense low-frequency sound for 1 min will generate low-frequency tinnitus, which shifts the MET channels towards the hyperpolarizing side which leading increase in EP and very-low-frequency sound and spontaneous contraction of the middle ear muscle, accompanied by a change in EP and movement of endolymph. Lastly, acute noise trauma can lead to alteration of MEP channels, which leads to increased EP (Noreña, 2015).

The second mechanism is excitatory drift in the operating point of the inner hair cells. Any condition that shifts the tectorial membrane towards inner hair cells leads to prolonged depolarization of inner hair cells. This can result from pressure increase in the scala media, the detachment of the tectorial membrane from outer hair cell tips, stereocilium damage, or outer hair cell degeneration. The stereocilium rootlets can be altered by acute noise trauma. The third mechanism is NMDA receptors. The activation of NMDA receptors will cause salicylate-induced tinnitus, which results from an increase in cochlear firing. As the inhibition of cyclooxygenase activity, salicylate will lead to the accumulation of arachidonic acid, which alters the mechanical properties of membranes and increases the opening probability of NMDA receptors (Noreña, 2015).

2.1.4.2 Central Tinnitus

Central-type tinnitus is supported by the neural activity that is generated in the auditory centre. The auditory centre is said to play an active role in terms of generating the tinnitus-related activity, which is the case of noise trauma, where the cochlear activity has been reduced after trauma. Tinnitus is more common in profound hearing loss, where the nerve activity of the cochlea is very low or absent. A lot of central mechanisms have been proposed to account for the generation of tinnitus-related activity, and most of it being triggered by the reduction in cochlear activity. Tinnitus-related central changes may be triggered by a shift in the distribution of sensory inputs toward lower values. (Noreña, 2015).

The hearing loss will lead to reorganization of the tonotopic map, hyperpolarization of thalamic cell membranes, facilitation of non-auditory inputs, and an increase in neural sensitivity or gain. These central changes will alter the pattern of neural firing, producing neural hyperactivity at the cortical and subcortical level, changes in cortical or thalamocortical oscillating activity, and hypersynchrony in the cortex. The cochlear ablation procedure has been carried out a few weeks after noise trauma, which shows the abolishment of noise-induced hyperactivity in the inferior colliculus, and 12 weeks after noise trauma, which shows the noise trauma does not alter the noise-induced central hyperactivity. All of these suggest that there are two forms of central tinnitus that can be distinguished, which are peripheral-dependent central tinnitus and peripheral-independent central tinnitus (Noreña, 2015).

2.2 Mechanism of tinnitus

2.2.1 Cellular Level

The mechanisms of tinnitus generation are said to be generated at the cellular level, system level, and others. At the cellular level, the mechanism that is most extensively studied is an increase in neural synchrony. When a person has noise-induced hearing loss, this causes a reduction in neural input to the central auditory system. Therefore, an increased spontaneous firing rate (SFRs) will occur, and the location of SFRs is said to be in the dorsal cochlear nucleus. The neurons are firing the action potential in a synchronized fashion, which leads to an increase in neuronal activity. There are animal studies that demonstrated the increased neuronal firing in the medial geniculate body (MGB) in animals with tinnitus compared to those without tinnitus. Neuronal hyperactivity occurs due to auditory deprivation from the cochlea. (Saeed & Khan, 2021).

Next, changes in neurotransmission are also linked to increased neural synchrony. The loss of inhibitory drives will cause an action of the excitatory drive that will produce hyperexcitability, that perceived as tinnitus. Maladaptive plasticity is also at the cellular level; it is the ability of the nervous system to change and adapt via reorganization of neurons in response to new stimuli. This has been studied in relation to memory. The term maladaptive plasticity involves misdirected learning. For tinnitus, the initial ring may be due to cochlear damage, but persistent tinnitus or chronic tinnitus may be due to maladaptive changes in auditory and non-auditory structures (Saeed & Khan, 2021).

2.2.2 System Level

2.2.2.1 Auditory Structures in Tinnitus Pathology

At the system level, the auditory structures that are involved in tinnitus pathology are the dorsal cochlear nucleus, the inferior colliculus, the medial geniculate body, and the auditory cortex. The main mechanism of the dorsal cochlear nucleus (DCN) in the tinnitus generator includes increased neuronal synchrony. Hyperactivity in DCN is seen as the result of decreased auditory nerve input through the inferior colliculus, thus leading to elevated neuronal activity. An animal study has shown that salicylate-induced guinea pigs and rats have demonstrated increased excitability. (Saeed & Khan, 2021).

Next, the medial geniculate body (MGB) of the thalamus is the higher center that integrates auditory and limbic information. MGB is also implicated in tinnitus generation. An animal model demonstrated that there is hyperactivity that occurs in MGB, but there needs to be more investigation. MGB will project the amygdala (the component of the limbic system that processes emotions). The auditory cortex is the highest center where the auditory stimuli are finally processed. There are two studies that show that when the intensity of perceived tinnitus increased, there is an increase of gamma band activity in the contralateral auditory cortex, and there is increased gamma band activity in the right and left primary and secondary auditory cortex of tinnitus patients. (Saeed & Khan, 2021).

2.2.2.2 Non-Auditory Structures in Tinnitus Pathology

The non-auditory structures that are involved are parahippocampus, dorsal anterior cingulate cortex, ventral prefrontal cortex, insula, orbitofrontal cortex, posterior cingulate, and precuneus. The para-hippocampal area plays a role in auditory

habituation. Recent literature shows an increase in high-frequency activity in the right hippocampal area. Another research shows that the parahippocampus has shown increased connections with non-auditory areas in chronic tinnitus. (Saeed & Khan, 2021).

Next, the dorsal anterior cingulate cortex has evidence supporting a role in the tinnitus distress network. The study where tinnitus distress creates abnormal alpha and beta activity in subgenual ACC extending to pregenual and dorsal ACC and ventromedial prefrontal cortex, insula, and parahippocampal area. For the ventral prefrontal cortex, 3 parts of medical radio imaging (MRI) studies identified a decrease in gray matter in the subcallosal region, specifically in the ventral prefrontal cortex, in tinnitus patients compared to controls. Next, the insula has been implicated in tinnitus distress. Insula plays a role in the autonomic nervous system, and tinnitus distress is correlated with sympathetic activation. The alpha activity in the right and left anterior insula was seen in severe tinnitus patients' distress. This serves as evidence of the insula for tinnitus pathology. (Saeed & Khan, 2021).

Next, the orbitofrontal cortex is involved in emotional processing of sound, which is indicated in tinnitus distress networks. The findings supported by a study where they found tinnitus patients (females) were more emotionally responsive to tinnitus distress, and the synchronized connectivity of the OFC and insula increased. Lastly, the posterior cingulate cortex and precuneus. These consist of brain default networks consisting of the parahippocampal area, the posterior cingulate cortex, and the precuneus, and these three regions are more active during tinnitus perception (Saeed & Khan, 2021).

2.3 Types of sound and their features

Sound therapy uses several types of sound, and the efficiency effects on suppressing the tinnitus vary as different sounds have different features. There are many types of sound that are available and used in sound therapy. Sound that is being used widely in studies is white noise, as it can cover the widest frequency range (20 Hz to 20,000 Hz), and the emergence of other sound usage developed over the years, such as pink noise and nature sound. In terms of therapeutic sound, Kim et al. (2014) found that white noise (broadband noise) is the most superior in terms of tinnitus suppression, followed by narrowband noise, and followed by mixed sound. Therefore, white noise is being chosen in this study as the first sound. For nature sounds, Durai & Searchfield (2017) uses nature sound and found that rain sound was the most preferred and most effective in terms of reducing tinnitus loudness and annoyance, followed by ocean waves and cicadas. Therefore, the nature sound chosen in this study is rain sound. Different sounds have different features and characteristics, which will be further discussed below.

2.3.1 Characteristics of white noise

White noise is an unmodulated sound that has equal energy across differential bands due to the combination of sounds at different frequencies. The spectral density of white noise is flat and has the same intensity across the human audible frequency range (20 Hz to 20,000 Hz). It has an unlimited bandwidth with a linear spectrum. In terms of masking the tinnitus, using white noise as a sound therapy can act as a masker for different types of tinnitus. This is due to its wide band of frequencies and its ability to mask different sounds with different frequencies. White noise can also reduce the patient's perception of sound, and using white noise may be a successful treatment for many types of tinnitus (Ghasemi et al., 2023). According to Lai et al. (2023), white

noise sounds very noisy rustle as the human ear is sensitive to high frequency, and white noise is recognized as an effective sound cosmetic treatment for different nervous system diseases such as tinnitus, auditory hypersensitivity, mental distraction, and attention deficit hyperactivity disorder.

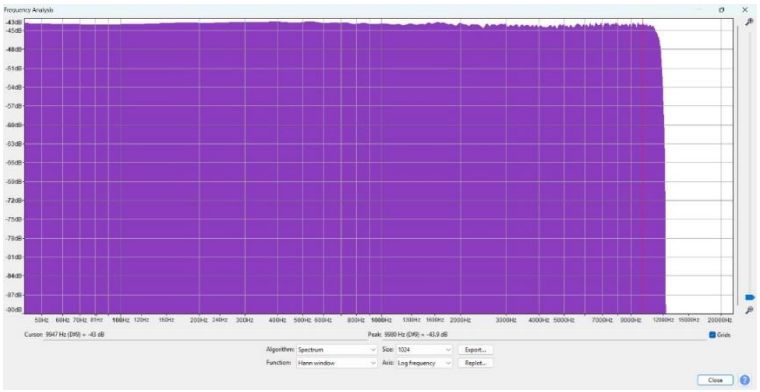

Figure 2.1: Sound Spectrum of White Noise in Resound Relief GN

2.3.2 Characteristics of natural sounds

There are various natural sounds that are available for tinnitus sound therapy. The characteristics of different natural sounds differ from each other. Natural sounds are said to have positive effects on human relaxation. The natural sound can be further divided into two categories, which are foreground and background sounds. The foreground sound is the sound that the listener's attention is specifically directed to, and the background sound is the sound that the listeners frequently hear or continuously hears. For instance, birds and water are the foreground sounds, meanwhile the traffic sounds are the background sound. (Han et al., 2022).

A study has been conducted by Yang & Kang (2013) where they used six parameters, such as SPL and the psychoacoustical parameters, which include loudness, sharpness, roughness, fluctuating strength, and tonality. The natural sounds used in the study consist of three categories, which are water sounds, wind sounds, and birdsongs.

The results are that water sounds have low fluctuation strength and a wide range of loudness; meanwhile, wind sounds have low fluctuation strength, a wide range of loudness, and low sharpness; meanwhile, birdsongs have high fluctuation strength, high sharpness, and low loudness. According to Jeong et al. (2019) where sound therapy was introduced to chronic subjective tinnitus using nature sounds (sound of waves and the water of a stream) and broadband noise. The result of the study shows nature sounds therapy group has an average decrease in tinnitus of 15.92 percent compared to 8.43 percent for the broadband noise therapy group. This means the nature sounds used in the study can suppress the tinnitus more than broadband noise. Barozzi, Del Bo, et al. (2016) findings found that nature and broadband noise result in similar reductions in the Tinnitus Handicap Questionnaire, and the nature sounds are said to affect top-down processing, which includes the positive effects on emotions. Natural ocean sound exposure is shown to be recommended for chronic tinnitus patients with complaints of low to middle-pitch tinnitus (Lim et al., 2021).

There are differences in people's preferences when choosing natural sounds. Based on the study done by Durai & Searchfield (2017), where the study was conducted among 18 participants using different natural sounds such as rain, surf, and cicadas sounds. Eleven out of 18 participants chose the rain sounds that are used in the experiment, five participants chose the surf sound, and two participants selected the Cicadas sound. Rain sounds are reported to be soothing and interact more with tinnitus due to their broad frequency spectrum and more consistent nature. The broadband noise is said to be the least preferred compared to the natural sounds. Another study done by Yang & Kang (2013) where human listeners prefer natural sounds such as water sounds and bird sounds, rejecting mechanical sounds such as vehicles and construction sounds.

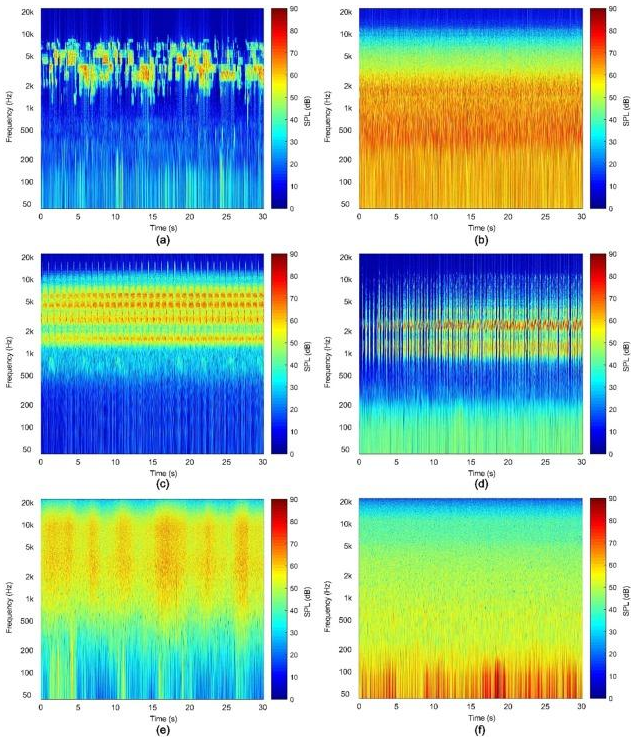

Figure 2.2: Time-frequency spectrograms of six natural sounds (a) bird, (b) water, (c) insects, (d) frogs, (e) wind, (f) rain

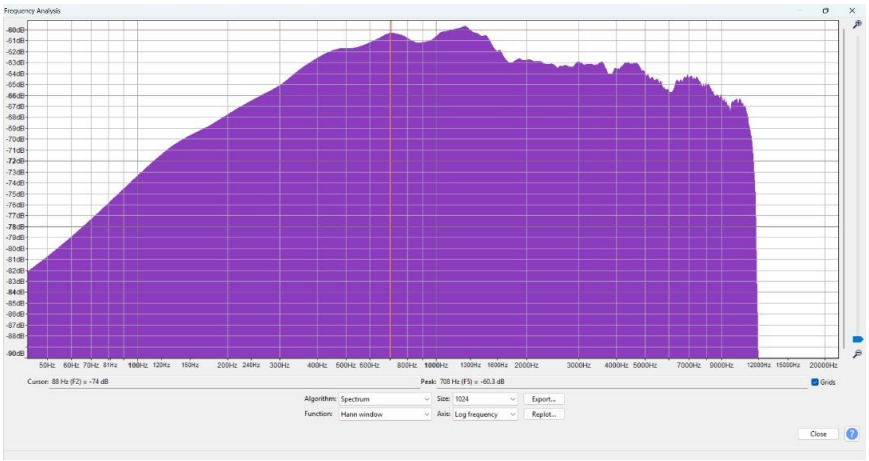

Figure 2.3: Spectrum of Rain Sound in Resound Relief GN

2.4 Mobile application that offers sound therapy for tinnitus

In the development of technology, there are diverse mobile applications that offer sound therapy, aiming to help tinnitus patients gain access to rehabilitation options for tinnitus. Nowadays, modern smartphones offer multiple sophisticated features that enable users to install different applications and store them in their mobile phones. The mobile application can be accessed through the Google Play Store for Android users and the App Store for iOS users.

According to studies conducted by Mehdi et al. (2020) where they conducted a systematic search and screening of smartphones, where they found a total of 34 mobile applications that offer rehabilitation options for tinnitus. Mobile Application Rating Score (MARS) scoring was used to rate mobile applications. MARS is known as a reliable and valid instrument for the quality assessment of smartphone-based medical apps or mHealth apps. A categorical distribution of smartphone applications was identified with two main categories which are tinnitus therapy comprises of tinnitus therapy (24 apps) and cognitive behaviour therapy (10 apps). From these 18 apps, the main focus is providing sound therapy, 7 apps for tinnitus masking, 4 apps for sound habituation, 4 apps for neuromodulation, and 3 apps for distraction. The remaining apps fall into tinnitus-therapy categories and cognitive behaviour therapy.

Based on the MARS rating, only 7 applications, which are Resound Relief, Tinnitus Therapy (LITE), SimplyNoise, Audio Notch, Wysa, Woebot, and MindShift, scored in the evidence-based subitem in the information category. For the mean MARS score, the apps that received good ratings are Resound Relief, Beltone Tinnitus Calmer, Sanvello-Stress and Anxiety Help, Woebot, and Youper (Mehdi et al., 2020). There is also a study conducted by Kutyba et al. (2022) in Poland, where they used the Resound Tinnitus Relief mobile application for 52 tinnitus patients. The study shows a reduction

in tinnitus severity when measured by the Tinnitus Handicap Inventory and Tinnitus Functional Index.

2.5 The factors that affect the effectiveness of sound therapy towards tinnitus patients

2.5.1 Duration of sound therapy

Sound therapy is said to yield positive impacts in tinnitus suppression, especially for those who have chronic tinnitus. Based on a study done by Jin et al. (2022) where they conducted research involving fifty-eight chronic tinnitus participants. The participants were assigned randomly to three groups. All three groups have different durations of sound therapy, such as 1 hour, 2 hours, and 3 hours. Then the effectiveness of sound therapy was measured by changes in tinnitus loudness level, visual analog scale, and the Korean version of the Tinnitus Primary Function Questionnaire (K-TPFQ). The outcome from these studies is that sound therapy has positive impacts on patients with tinnitus, especially those who have longer daily sound therapy hours. Therefore, sound therapy has proven beneficial when the duration of the sound is longer.

2.5.2 The Psychological and Emotional State of the Patient

Tinnitus will have an effect on the psychological and emotional state of a patient. Lewis et al. (2020) stated that ten percent of the population will experience of short period of tinnitus in their lifetime, but up to 7 percent of patients are suffering from persistent and bothersome tinnitus. These patients may be suffering from anxiety, depression, inability to focus on daily tasks, and sleep disturbance, which will

significantly impair their quality of life. A study done by Fang et al. (2024) analyzed the electrocardiogram (ECG) signals from tinnitus patients who are undergoing sound therapy. The findings revealed that patients experienced emotional changes during therapy sessions. These changes are correlated with the effectiveness of tinnitus sound therapy.

2.6 The Effect of Sound Therapy in the Auditory Network

There are diverse types of sound used in sound therapy, such as white noise, narrow band noise, brown noise, pink noise, and natural sounds. In people with tinnitus, sound therapy will yield positive effects on tinnitus suppression, and each of them elicits different effects on the auditory network in terms of suppression effect. Another study done by Henry et al. (2004) where they found that the natural sound had more significant effects in reducing tinnitus annoyance compared to technical sounds such as white noise.

A study done by Lv et al. (2021), where they analysed the functional connectivity in the auditory network before and after sound therapy in tinnitus patients. They analysed the functional connectivity within the auditory network and the functional connections between other brain regions and the auditory network. After multiple comparison corrections, the functional connectivity of the left primary auditory cortex (PAC) and secondary auditory cortex (SAC) remains significant. This outcome indicates that after the sound therapy, the brain region that is closely related to the auditory signal processing has demonstrated altered functional connectivity. The functional connectivity increased after sound therapy in PAC. Another study also indicated an increase in regional brain activity of the PAC after the sound therapy.

These two studies demonstrated that there is an increase in regional brain activity of PAC after the sound therapy.

The exposure to external sounds will prompt structural and functional changes in the central auditory system, and it can also affect the limbic region (amygdala and hippocampus). The stimulation of sound will facilitate tinnitus habituation by decreasing the tinnitus strength signal by increasing the background neuronal activity in the auditory system. (Barozzi, Del Bo, et al., 2016).

2.7 Measurement of tinnitus pitch and tinnitus loudness

The tinnitus pitch and loudness vary among people with tinnitus. Some people will perceive high-frequency tinnitus, some will perceive mid-frequency tinnitus, etc. Therefore, psychoacoustic measures of tinnitus are obtained based on two reasons which are to define the auditory attributes of tinnitus and to define the potential effects of the external sound on tinnitus when given sound treatment. (Henry, 2016). Precise tinnitus matching is a key measure that will enable appropriate adjustment to individualized sound treatments to suppress or reduce the perception of tinnitus. (Neff et al., 2019).

Tinnitus pitch refers to its perceived frequency or the center frequency of a spectrum of nontonal tinnitus. One of the best standard methods to measure the tinnitus pitch is by conducting tinnitus pitch matching. For pitch matching, the frequency of the selected tone will be varied, and the patient will then be asked to select the best tone that matches the pitch of their tinnitus. In most cases, when pitch matching is conducted, the patient will match the tinnitus pitch to a tone greater than 3 kHz. Tinnitus loudness can be measured by loudness matching. This loudness matching

originated with Fowler (1938), who developed a test that aims to balance the loudness of tinnitus in one ear with the loudness of a tone that is introduced in the contralateral ear. The comparison tone level is expressed in dB SL (Sensation Level) (Henry, 2016).

2.8 Management for tinnitus patients

2.8.1 Sound Therapy

The most extensive research management for tinnitus patients is sound therapy. Sound therapy is a common treatment for tinnitus. The original idea is to partially or completely mask the tinnitus sound using broadband noise delivered by sound generators or using the hearing aids for a few hours each day. Over several periods of time, patients with tinnitus reported that the tinnitus sound became less prominent, quieter and become easier to bear and less aversive. (Martin Pienkowski, 2019). Sound therapy is thought to reduce the emotional consequences of tinnitus. Some patients with tinnitus will experience residual inhibition following total or partial masking. Sound therapy can promote tinnitus habituation by decreasing the contrast between environmental sound and tinnitus sound (Tunkel et al., 2014).

2.8.2 Education and Counselling

Education and counselling can reduce the anxiety and fear caused by tinnitus by helping the patient to understand tinnitus and increase the understanding of the need and procedure of tinnitus rehabilitation. By counselling, healthcare providers can help in providing the motivation for tinnitus rehabilitation and giving help in psychological support to overcome tinnitus (Tunkel et al., 2014). Richard S. Tyler et al. (2012) reported that 18 people in tinnitus rehabilitation group who received only counselling

for 18 months have 25 percent of rehabilitation effect based on the change observed in tinnitus questionnaire scores. Healthcare providers should include the association between hearing loss and tinnitus and include the lifestyle factors that can have positive or negative effects on tinnitus rehabilitation. Information such as protection from noise such also be included in the counselling.

2.8.3 Cognitive Behavioural Therapy

Cognitive behavioural therapy (CBT) teaches the skills to identify negative thoughts that cause distress and restructure the thoughts. Hesser et al. (2011) reviewed 15 studies and the outcome is CBT have sustained benefits on tinnitus-specific outcome measures and smaller benefits for mood outcomes and there are significant improvements in depression that are associated with tinnitus when CBT applied. Most CBT for tinnitus studies involves 8 to 24 weekly sessions where each session lasted around 60 to 120 minutes. The benefits of CBT are found in 12 months and longer of CBT application. CBT can be provided by mental health professionals (MHP) and audiologists or other health professionals trained in cognitive behavioural treatment can also provide this treatment (Tunkel et al., 2014).

2.9 Measurement of suppression effect

The suppression effect can be measured using distortion products otoacoustics emission (DPOAE). The cochlear function plays an important role in tinnitus perception generation. The function of cochlear can be tested objectively and noninvasively using otoacoustic emission specifically distortion product otoacoustic emission (DPOAEs). DPOAEs amplitudes are significantly reduced in 93.3 percent of