COMPARISON OF TEMPORAL PROCESSING ABILITIES OF NORMAL HEARING INDIVIDUALS WITH AND WITHOUT MISOPHONIA

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CERTIFICATE

This is to certify that this dissertation entitled **'Comparison of temporal processing abilities of normal hearing individuals with and without misophonia'** is a bonafide work submitted as a part of the fulfilment for the degree of Master of Science (Audiology) of the student Registration Number: P01II21S0058**.** This has been carried out under the guidance of the faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DEDICATED TO MY FAMILY

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Abstract

The study focused on comparing the temporal processing abilities of normal-hearing individuals with and without misophonia. Temporal processing skills in misophonia individuals were assessed using a battery of tests including gap detection, duration discrimination, temporal modulation transfer function, and frequency pattern tests.

60 individuals with normal hearing were taken into consideration for this investigation and divided into two groups with and without misophonia (30 each). Misophonia Assessment Questionnaire (MAQ) was used to assess the misophonia severity. The temporal tests (Gap detection, duration discrimination, temporal modulation transfer function, and frequency pattern tests) were carried out on Matlab platform using psychoacoustic toolbox. .

The results depicted no statistically significant differences between the individuals with and without misophonia on all the temporal processing tests. Also, there was no statistically significant correlation between the severity of misophonia and performance in each test. The finding from the study showed that misophonia does not appear to have a significant impact on temporal processing abilities in individuals with normal hearing. Further research may be necessary to explore the relationship between misophonia and other auditory or cognitive processes.

Keywords: misophonia, temporal processing, MAQ

CHAPTER 1

INTRODUCTION

Misophonia is a condition where the individual has an adverse physiological or emotional response to specific sounds (Jastreboff & Jastreboff, 2001) The person's reaction to sound depends upon the physical characteristics of sound and the environment in which it is presented. According to the consensus definition by Swedo et al (2022), misophonia is a condition of reduced tolerance to particular sounds or stimuli associated with such sounds. This is a newly defined psychiatric condition, which is characterized by hatred of ordinary human sounds which may not be aversive to others (Schröder et al., 2014). Stimuli that cause adverse reactions are called "triggering sounds" or "misophonic sounds", characterized by having the same pattern irrespective of their physical properties like intensity, frequency, harshness or decibel level (Ferrer-Torres et al, 2022) Triggering factors for misophonia varies from person to person. Some individuals have issues with soft sounds like chewing but do not have a problem with loud music. For some individuals, misophonia is present in some environments, which may not be present in other environments (eg: annoyance with chewing sound only at home and not present in public places). There are various triggering factors reported in the literature, such as chewing/eating, typing, nail scratching, pen clicking, clock ticking etc (Edelstein et al., 2013; Jastreboff et al, 2001; Rouw et al, 2018; Schröder et al., 2013) Among the triggering sounds, the majority of the sounds are produced by humans that produce unpleasant reactions and among these, the majority are related to orofacial movements. Other than the auditory triggers, visual stimuli can also cause aversive reactions such as leg swinging (Edelstein et al., 2013;

Schröder et al., 2013). Misophonic individuals may have multiple triggering factors and may use different coping mechanisms for these situations. The common coping mechanisms include avoiding situations eliciting aversive reactions, and distracting oneself by listening to music and other sounds. (Edelstein et al., 2013; Schröder et al., 2013)

Reactions to the triggering sounds include physiological and emotional responses (Jastreboff & Jastreboff, 2001) Under behavioural responses, the individual may experience anger, disgust, irritability and under physiological responses, they may experience accelerated heart rate, sweating, anxiety, breathing difficulties etc. Misophonia brings distress and a decline in the quality of life (Duddy et al, 2014) Because of the need to confront, avoid, or escape the triggering situations can have an impact on a person's relationships with family and friends and their ability to focus in school or at work.

Most of the literature indicates that misophonia onset is during adolescence or adulthood (Edelstein et al., 2013; Palumbo et al., 2018; Sanchez & Silva, 2018), and the mean age of diagnosis is 37 years (Schröder et al., 2013) Modern classification systems such as the Diagnostic and Statistical Manual of Mental Disorders, 4th edition, and International Classification of Diseases, 11th revision, do not recognize misophonia; hence, there is little awareness about it in the general population. Misophonia shares characteristics with other disorders, such as obsessive-compulsive disorder (OCD), attention deficit disorder (ADD), or post-traumatic stress disorder (PTSD)(Ferreira et al., 2013; Rouw et al., 2018; Webber et al., 2014). Other literature shows a significant comorbidity rate between misophonia and other mental conditions such as depression, OCD, and anxiety (Bernstein et al., 2013; Cusack et al., 2018). Comorbidity has also been noted with neurological conditions such Tourette's syndrome and problems of the auditory system (Naguy et al., 2022; Neal et al., 2013). Tinnitus and hyperacusis are closely related to misophonia in terms of modifications to the auditory system because of their shared symptomatology (Ferrer-Torres et al., 2022). In some cases, they can occur as comorbid conditions also. Auditory processing may be affected in misophonia individuals as there is hyperactivation in the anterior insular cortex, ventromedial prefrontal cortex (vmPFC), posteromedial cortex (PMC), hippocampus, and amygdala (Kumar et al., 2017).

Central auditory processing (CAP) is the ability to perceptually receive stimuli within the central auditory nervous system (CANS) and conduct the subsequent neurobiological activities that give rise to the electrophysiological auditory action potentials (Bellis & Bellis, 2015). Domains of auditory processing include temporal processing, binaural interaction, binaural fusion, binaural integration, binaural separation, and auditory closure. Auditory temporal processing can be defined as the perception of sound or of the alteration of sound within a restricted or defined time domain (Friedman, 1991). Temporal processing is the ability to process acoustic stimuli over time. This has a significant role in complex higher-level processing, such as speech perception in quiet and background noise, localization, discrimination, pattern processing, binaural integration, and binaural separation (Musiek et al., 2005). Temporal resolution refers to the ability to detect changes in stimuli over time (Moore, 1957). Temporal ordering refers to processing multiple auditory stimuli in their order of occurrence (Hirsh, 1974). Duration discrimination is the ability to detect a change in the duration of auditory stimuli (Moore, 1957). The present study focuses on these three temporal processes. Temporal processing deficits are seen in patients with insular cortex stroke (Bamiou et al., 2006). Since misophonia individuals have abnormal activation of the anterior insular cortex (Kumar et al., 2017), temporal processing deficits can be expected in this population.

Poor temporal processing abilities and the absence of right ear advantage are reported in individuals with tinnitus compared to the controls (Raj-Koziak et al., 2022). It is also reported in the literature that even with normal auditory thresholds, there may be some possibility of abnormality in central auditory processing functions (Schröder et al., 2014). Although closely associated with tinnitus, a dearth of literature probes into the temporal processing deficits in individuals with misophonia. This study probes to examine the difference in the temporal processing between individuals with and without misophonia.

1.1 Need for the study

It is reported in the literature that individuals with misophonia showed normal results in standard hearing tests and hence showed no attributable peripheral audiological deficits (Edelstein et al., 2013). The pathways involved in tinnitus and misophonia are similar (Jastreboff et al. 2004). In both conditions, the trigger is perceived in the peripheral auditory system, which is then connected to the subcortical and cortical auditory centers. These centers activate the limbic and autonomic systems, which can result in tinnitus and misophonia. Also, there is abnormal activation of the non-classical auditory pathway in both tinnitus and misophonia (Palumbo et al., 2018). Previous studies show temporal processing deficits in individuals with tinnitus (Raj-Koziak et al., 2022). Since the pathways for tinnitus and misophonia are similar, one can expect a similar auditory temporal processing deficit in individuals with misophonia, too. Hyperactivation of the right insula, right anterior cingulate cortex, and right superior temporal cortex are observed in individuals with misophonia (Schröder et al., 2019) This suggests that there could be some temporal deficits seen in individuals with misophonia. The neuroaudiological model by Aryal & Prabhu (2022) also shows that there are alterations in the higher structures of the brain in misophonia individuals which may indicate some kind of processing difficulties. The study focuses on determining if there is any change in specific processes of central auditory processing, particularly temporal processing, in individuals with misophonia.

A three-case report stated persistent hyperacusis in individuals with insular cortex damage (Boucher et al., 2015). They reported a reduced level of loudness, discomfort level, increased amplitude of P3b in late latency auditory evoked potential, and impairments in temporal processing, which was seen in random gap detection, frequency, and duration patterns tests. Turner et al. (2008) measured gap detection thresholds (GDT) in rats with salicylate-induced tinnitus and hyperacusis and reported a significant deficit in GDT. There is other literature that also indicates temporal processing deficits in the hyperacusis group (Ahmmed & Mukherjee, 2021; Salloum et al., 2016). Since misophonia, tinnitus, and hyperacusis share similar mechanisms, we can expect temporal processing deficits in the misophonia group also. This study focuses on determining if there is any change in specific processes of central auditory processing, particularly temporal processing, in individuals with misophonia. Ila et al. (2023) studied temporal processing abilities in misophonia individuals by assessing random gap detection in noise, duration pattern test, and frequency pattern test. They did not find significant differences between individuals with and without misophonia. However, this study aims to understand temporal processing better by assessing through multiple temporal tests such as gap detection test, duration discrimination test, frequency pattern test, and temporal modulation transfer function.

1.2 Aim of the study

The study aimed to evaluate temporal processing in individuals with misophonia.

1.3 Objectives of the study

- To measure the differences in gap detection thresholds between individuals with and without misophonia
- To measure the differences in duration discrimination thresholds between individuals with and without misophonia
- To measure the differences in pitch pattern test between individuals with and without misophonia
- To measure the differences in temporal modulation transfer function thresholds between
- To correlate the performance of individuals with misophonia across the tests and degree of misophonia.

1.4 Null hypothesis

1. There is no difference in gap detection thresholds between individuals with and without misophonia

2. There is no difference in duration discrimination thresholds between individuals with and without misophonia
3. There is no difference in pitch pattern test scores between individuals with and without misophonia
4. There is no difference in temporal modulation transfer function thresholds between individuals with and without misophonia.
5. There is no correlation between the performance of individuals with misophonia across tests and the degree of misophonia.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Definition

Misophonia is a condition where the individual has adverse physiological and emotional responses to certain sounds (Jastreboff & Jastreboff, 2001). The reactions could be emotional and/or physiological, and it depends on the environment and the physical characteristics of the sound. Misophonia is a newly defined psychiatric condition characterized by the hatred of ordinary human sounds (Schröder et al., 2014). Misophonia is an affective sound-processing condition in which people experience strong negative emotions (anger and anxiety) in response to everyday sounds, such as those generated by other people eating, drinking, chewing, and breathing which may be normal for others (Kumar et al., 2017) It is a chronic illness in which a person suffers strong emotional sensations and autonomic arousal in response to certain noises (Edelstein et al., 2013) Misophonia is characterized by an excessively intense response to sound that has a particular pattern and/or meaning to them (Jastreboff & Jastreboff, 2014) In Greek, misophonia is translated to "hatred of sound," but this definition is not completely true as the person does not have hatred towards all sounds. It is better described as decreased sound tolerance to certain sounds, as quoted by Jasterboff and Jasterboff. Most of these sounds are softer and are related to a person or animal.

2.2 Prevalence

Misophonia can be present in isolation or association with other conditions, such as tinnitus and hyperacusis. Although some symptoms are similar to these diseases, misophonia is different from them, and a person may have multiple conditions at once. Studies show that misophonia onset can occur during adolescence (Palumbo et al., 2018) or during adulthood (Sanchez et al., 2018). Some studies claim there is no specific age range for misophonia because it can occur at any age (Potgieter et al., 2019).

Few case studies and clinical studies have been done on misophonia to determine its prevalence. Hadjipavlou et al. (2008) reported that 10-60% of individuals with tinnitus also have misophonia. Another study also shows that 60% of individuals with tinnitus have misophonia (Jastreboff & Jastreboff, 2002). Wu et al. (2014) conducted an online questionnaire survey and found that 19.9% of US undergraduate students experienced misophonia. In a study done on Chinese graduates, misophonia was seen in 20% out of 415 graduates (Zhou et al., 2017). In a study by Naylor et al. (2021), 49.1% of the study sample population of UK undergraduate medical students had clinically significant misophonia. Turkey's population-based study showed a prevalence of 12.8%, although 78.9% of the participants mentioned at least one disturbing sound (Kılıç et al., 2021). Germany population-based misophonia prevalence study showed a rate of 5% (Jakubovski et al., 2022). In a study done on the hearing-impaired population, misophonia was found in 57% of them (Jastreboff & Jastreboff, 2002).

Individuals with misophonia commonly state that the onset of the condition starts in childhood. (Edelstein et al., 2013) In his study, he took 11 misophonic participants. Two subjects claimed that with age they developed stronger coping mechanisms, while five subjects claimed that with age the condition deteriorated and three subjects claimed no change over time. Although the reasons for the different trigger accumulation and severity between misophonic are not fully understood, it seems that frequent and extended exposure to a sound may be a significant factor. Also, they propose that misophonia might have familial or hereditary components as few of the subjects report that many close family members have misophonic-like symptoms (Edelstein et al., 2013). In a study done on 42 Dutch patients who reported misophonia, they found that the mean age of onset was 13 years, and 52% of the participants were males (Schröder et al., 2013). Jager et al. (2020) did a study to determine the phenomenology, comorbidity, and demographics of the misophonia sample that was referred to their center. Out of 779 referred subjects, 575 of them had misophonia. They reported that the mean age of onset was 13.17 years, and the mean age of admission was 34.17 years. In this, 93% of the subjects claimed a gradual onset of symptoms, and the onset of symptoms was not considerably earlier in females compared to males. Also, they recorded that 33% of the subjects had a positive family history of misophonia. Among the misophonia-confirmed patients, 72% of them had no comorbid Axis I psychiatric disorder, 22% had one comorbid disorder, and 6% had two or more comorbid disorders. The most commonly noted comorbid disorders were depressive disorder (6.8%) and obsessive-compulsive disorder (2.8%) (Jager et al., 2020). A study done on patients with depression showed a misophonia prevalence rate of 8.5 to 12.76%, and anxiety had the strongest positive correlation with the severity of misophonia symptoms (Siepsiak et al., 2020). A large-scale study done on misophonia which analyzed personal, developmental and clinical characteristics showed misophonia symptoms started in childhood or early adolescence, one-third of the subjects reported family members experiencing similar symptoms.

In contrast to the other half, who reported a variety of ailments, half of the participants reported no associated clinical disorders. The severity of the misophonic symptoms was only correlated with post-traumatic stress disorder (PTSD) (Rouw & Erfanian, 2018).

In the Indian context, there are very few studies done on misophonia prevalence. One of the studies that were done to check the prevalence of misophonia in college-going students showed a rate of 15.85% with no appreciable variation between genders (Patel et al., 2022) But there was a slight predominance in females compared to males, which was seen in earlier investigations also. The causes for the high prevalence rate in India could be consanguineous marriage and exceeding acceptable standards of noise level exposure in different cities and towns of India (Patel et al., 2022). Another study checked the prevalence of misophonia among Mysore University students, which showed a rate of 47.6% (Aryal & Prabhu, 2022a). Out of this, 47.6% and 25.93% reported tinnitus as a comorbid condition, and 27.16% reported hyperacusis as a comorbid condition. This shows that misophonia can occur in isolation or with other associated disorders. A family history of misophonia had been stated by 8.64% of individuals, and they did not find any significant association between gender and misophonia prevalence. (Aryal & Prabhu, 2022) All these prevalence studies indicate that misophonia can occur in diverse cultural and socioeconomic groups.

2.3 Characteristics

Individuals with misophonia may present behavioral or physiological responses or even both to the trigger sounds. Misophonic individuals experience various emotions, including anger, irritation, disgust, perceived loss of control, etc.

(Rouw & Erfanian, 2018). Apart from these behavioral reactions, subjects may also show physiological responses such as pressure in the arms, chest, and head, clenching or tightening of muscles, increase in blood pressure, heart rate, body temperature, sweaty palms, and breathing difficulties in response to triggering sounds (Edelstein et al., 2013) These symptoms usually start during adolescence and the mean age of onset is 13 years (Schröder et al., 2013) In an exploratory interview, it was found that the worst triggering sounds are chewing/eating/crunching sounds, lip smacking, pen clicking and clock ticking (Edelstein et al., 2013). Other sounds that trigger misophonia are low-frequency bass, footsteps, finger tapping, whistling, and typing(Edelstein et al., 2013). Jager et al. (2020) reported that most of the subjects claimed eating sounds (96%) as the triggering sounds, followed by nasal and breathing sounds (85%). Auditory and visual triggers can elicit Misophonia. Most triggers are auditory-based, but some visual triggers are reported, such as repetitive movements (68%) (Jager et al., 2020). Compared to auditory triggers, visual triggers had less effect. Individuals reported stronger reactions when both auditory and visual triggers co-occurred. An interesting characteristic seen in misophonic is that self-evoked trigger sounds do not cause any reactions, whereas when other individuals produce those sounds, it elicit reactions (Edelstein et al., 2013). Another interesting characteristic noted is the role of context on aversive responses. Most individuals show aversive responses when humans produce the triggering sound, but when animals or babies produce the same sound, they don't find it unpleasant (Edelstein et al., 2013). An Indian study reported that most misophonic individuals claimed more than one sound as a trigger, and the reported triggering sounds are chalk scratching, loud sounds, chewing, teeth clicking, and benches moving. (Aryal & Prabhu, 2022) In an experiment, the physiological response was calculated using skin conductance response (SCR) measurements, which revealed enhanced autonomic responses to trigger sounds but not visual stimuli (Edelstein et al., 2013). Also, it has been shown that alcohol reduces the intensity, although caffeine may have the opposite effect. There are cases of misophonic having disrupted auditory/sensory processing (Edelstein et al., 2013; Schröder et al.,2014.; Wu et al., 2014). As opposed to hyperacusis, misophonia is more sensitive to the emotional reaction it elicits. (Tyler et al., 2014). Other disorders that share misophonia symptoms are obsessive-compulsive disorder (OCD), attention deficit disorder (ADD), post-traumatic stress disorder (PTSD), auditory processing disorder, tinnitus, and hyperacusis (Edelstein et al., 2013). Few misophonic individuals reported that when treated with antianxiety and antidepressant medications, it lessened the impacts of misophonia (Edelstein et al., 2013).

Misophonic individuals exhibit several coping strategies. These include avoiding triggering situations, imitating the triggering sounds or the action that causes them to "cancel out" or "retaliate," using earplugs and headsets to distract oneself by listening to music or by reciting calming mantras and asking others to stop making the sounds (Edelstein et al., 2013) Jager et al. (2020) reported various coping mechanisms such as listening to music and walking away from triggering situations which were most used. Other than these methods, they coped by making sounds in the same rhythm, e.g., chewing or typing, and using earplugs. Aryal et al. (2022) claimed that individuals use multiple coping strategies. The most commonly used method is avoiding certain situations, sleeping, listening to music at high volume, and ignoring the triggering sound by indulging in some other activity.

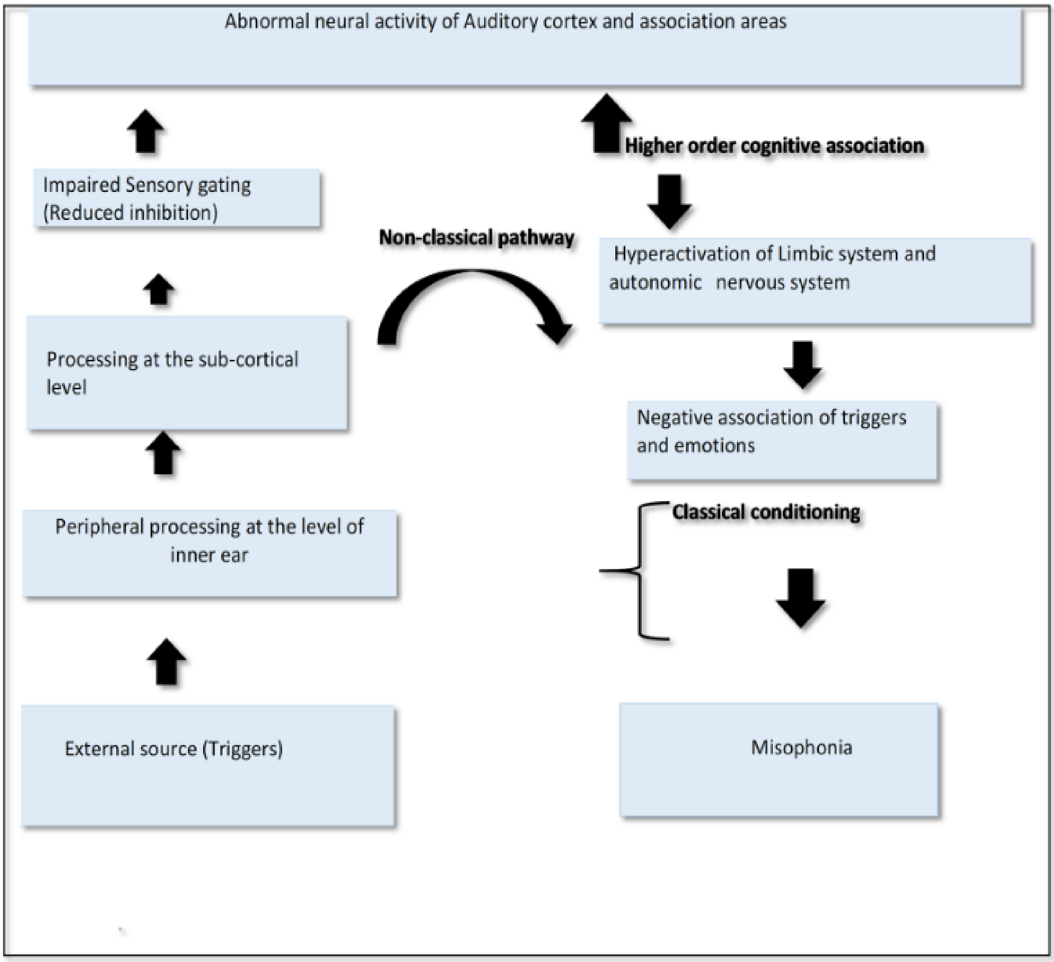
2.4 Neuroaudiological model

Misophonia occurs due to abnormal activation of the auditory cortex, limbic system, and non-classical auditory pathway (Schröder et al., 2019). Functional magnetic resonance imaging (fMRI) studies on misophonia show hyperactivation of the right insula, anterior cingulate cortex, and right superior temporal cortex for misophonic video clips (Kumar et al., 2017). The anterior insular cortex (AIC) is known to differentiate between trigger sounds and neural sounds, and studies have shown interaction in AIC bilaterally (Kumar et al., 2017). Another fMRI study shows more significant activity in the right insula, right anterior cingulate cortex, and right superior temporal cortex, where ACC and insula are linked to the detection and selection of emotionally relevant information and the right superior temporal cortex is linked to selective auditory attention which is crucial for processing emotionally salient sounds (Schröder et al., 2019). One of the fundamental components of the limbic and autonomic nervous system is AIC; hence, hyperactivation of AIC results in the abnormal activation of these systems. A model suggests hyperactivation of mirroring neurons in the misophonia group, which is supported by enhanced resting state-functional magnetic resonance imaging (rs-fMRI) between the auditory and visual cortex and the ventral premotor cortex responsible for orofacial movements, enhanced functional connectivity between auditory cortex and orofacial motor area and enhanced activation of orofacial motor area in response to trigger sounds (Kumar et al., 2021). Even though mirroring occurs in healthy individuals in misophonia, it is stronger and specific to trigger sounds. Brain structural measurements showed enhanced myelination within the ventromedial prefrontal cortex (vmPFC) (Kumar et al., 2017).

Event-related potential measurement during an oddball task showed reduced N1 amplitude for the misophonia group, which suggests an auditory information processing deficit at a low level (Schröder et al., 2014). However, auditory brainstem response findings did not show a significant difference between the individuals with and without misophonia (Aryal & Prabhu, 2023). The first identified neurobiological marker for misophonia was reduced deviant MMN amplitude, but they did not observe a significant difference with respect to the latency of the MMN peaks (Schröder et al., 2013). Misophonia individuals did not show altered response inhibition in the Stop Signal Task, but they exhibited longer stop signal delays and response bias favoring accuracy over speed (Eijsker et al., 2019). Considering all these neurophysiological and neuroradiological findings, Aryal et al. (2022) proposed a neurobiological model that shares characteristics with the tinnitus and hyperacusis neurophysiological model. The model states that the external triggering sounds will be processed at the level of the inner ear and sent to higher-order processing structures. Impaired sensory gating results in abnormal activation of the auditory cortex and association areas, and due to abnormal activation of the non-classical auditory pathway, the limbic and autonomic nervous system is hyperactivated. This leads to a negative association of triggers and emotions, resulting in misophonia. (Figure 2.1)

Figure 2.1

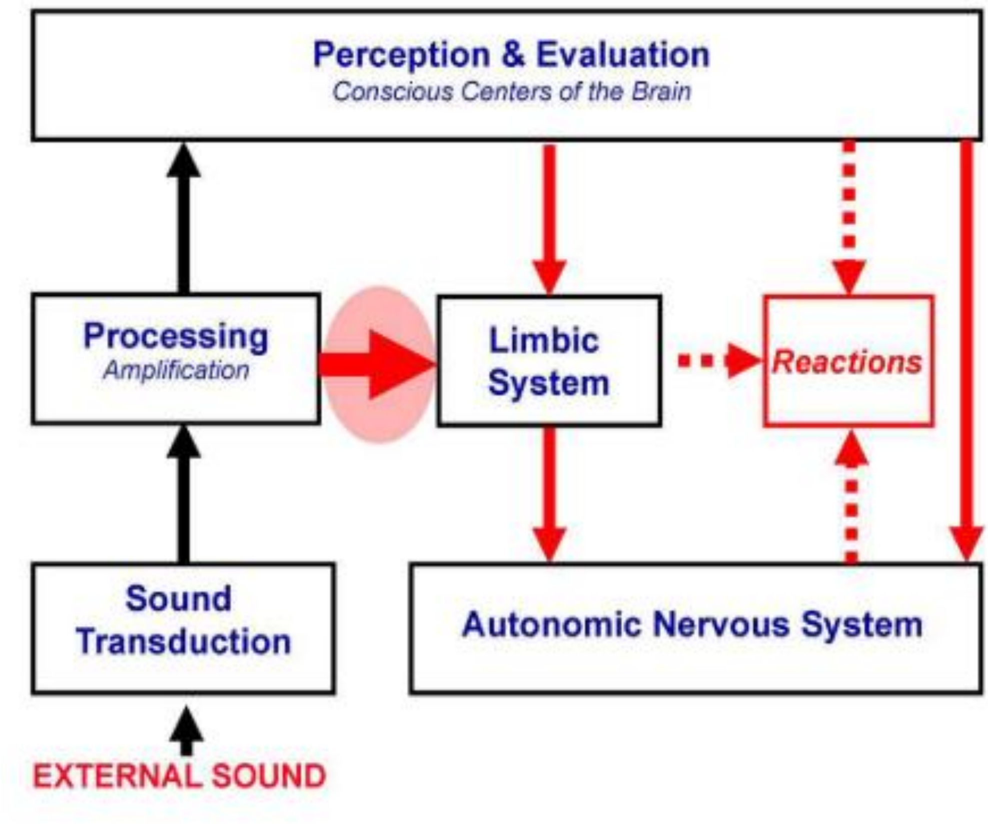
Neuroaudiological model of misophonia (Aryal & Prabhu, 2023)



Jastreboff & Jastreboff (2023) proposed a neurophysiological model based on the auditory, limbic, and autonomic nervous systems involving the brain's conscious and subconscious parts. The model states that the abnormal functional link between the subconscious part of the auditory system and the limbic and autonomic nervous system is the root cause of misophonia. The subconscious brain is dominant, and the subconsciously conditioned reflexes are vital for misophonia. Treatments based on this model showed a remarkable success rate with lasting improvement and no relapse (Jastreboff & Jastreboff, 2014), and the model is validated by the patient's observations.

Figure 2.2

Neurophysiological model by Jastrebof et al. (2023)



2.5 Temporal processing in misophonia

Ila et al. (2023) studied temporal processing in individuals with misophonia by assessing gaps in no, duration, and frequency pattern tests. They considered 30 misophonia and 30 control participants and measured misophonia severity through the Misophonia Assessment Questionnaire. The need mentioned in the study was the reduced N1 component observed in Schröder et al. (2014) study, which may affect temporal processing. However, they did not find any significant difference between the control and misophonia groups in all three temporal tests. This suggests no difference in auditory processing between individuals with and without misophonia. The article mentioned above studied temporal processing by assessing three temporal tests, whereas this study focuses on studying temporal processing by assessing gap detection in noise, duration discrimination in noise, temporal modulation transfer function test (under four frequency modulation rates), and frequency pattern test. Ila et al. (2023) researched only temporal resolution and temporal ordering, while the present study evaluated temporal resolution, temporal ordering, and temporal discrimination to understand temporal processing better.

CHAPTER 3

METHODS

3.1 Study design

The study uses standard group comparison where the temporal processing test results are compared between the normal-hearing individuals with misophonia and normal-hearing individuals without misophonia.

3.2 Ethical considerations

Each subject was briefed about the objectives of the study, and informed consent was obtained from all the participants. All procedures carried out in this study complied with the guidelines for bio-behavioural research (Venkatesan & Basavaraj, 2009).

3.3 Participants

A total of 60 participants in the age range of 18-30 years are considered for this study and are divided into two groups: the control and the comparison group. The control group consisted of normal-hearing individuals without misophonia, and the comparison group consisted of normal-hearing individuals with misophonia. Both groups had 30 participants each.

3.4 Participant Selection Criteria

3.4.1 Control group

30 individuals with normal hearing sensitivity (Mean age: 22.4 years; SD- 2.28; males- 12, females-15) with the following criteria were included in this group

- Pure tone threshold average (0.5 kHz, 1 kHz, 2 kHz, and 4 kHz) of less than or equal to 15 dB
- No middle ear pathology, which is confirmed through otoscopy and immittance.

- There is no history of ontological complaints, noise exposure, ototoxic medications, vestibular migraine, tinnitus, hyperacusis, diabetes, hypertension, anxiety, or depression.

3.4.2 Misophonia group

Thirty individuals with misophonia having normal hearing sensitivity sensitivity (Mean age: 22.03 years; SD- 2.97; males- 1, females-29) with the following criteria were included in this group.

- Pure tone threshold average (500Hz, 1 kHz, 2 kHz, and 4 kHz) of less than or equal to 15 dB
- No middle ear pathology, which is confirmed through otoscopy and immittance.
- No history of ontological complaints, noise exposure, ototoxic medications, vestibular migraine, tinnitus, hyperacusis, diabetes, or hypertension.
- Misophonic individuals were selected according to the diagnostic criteria (Schröder et al., 2013) as shown below. Misophonia diagnosis is given only to those individuals who reported all the symptoms given in criteria.

Diagnostic criteria for misophonia

1. The presence or anticipation of a specific sound, produced by a human being (e.g., eating sounds, breathing sounds), provokes an impulsive aversive physical reaction which starts with irritation or disgust that instantaneously becomes anger.
2. This anger initiates a profound sense of loss of self-control with rare but potentially aggressive outbursts.

3. The individual tends to avoid the misophonic situation, or if they do not avoid it, endures encounters with the misophonic sound situation with intense discomfort, anger or disgust.
4. The individual's anger, disgust, or avoidance causes significant distress.
5. Other disorders, such as obsessive-compulsive disorder and post-traumatic stress disorder, do not better explain the person's anger, disgust, and avoidance.

3.5 Procedure

Through a calibrated audiometer, behavioral thresholds were obtained using a modified version of the Hughson-Westlake procedure (Carhart & Jerger, 1959), where 10 dB intensity was reduced whenever the participant heard the sound and 5 dB intensity was increased when the participant didn't hear the sound. The lowest level at which the patient responded for at least 2 out of 3 trials was considered the threshold. Normal middle ear function was confirmed through otoscopy and immittance. Middle ear analysis was done through a calibrated tympanometer (Grason Stadler Inc Tympstar Pro Middle ear analyzer, GSI VIASYS Healthcare, WI, USA) with a probe tone frequency of 226 Hz. Also, both ipsilateral and contralateral reflexes were obtained for 0.5 kHz, 1 kHz, 2 kHz, and 4 kHz.

3.5.1 Assessment of misophonia

The characteristics of misophonia include provocation of emotional and physiological responses such as anger, disgust at certain sounds, physical buildup of pressure in the chest, and avoidance of such situations. The severity of misophonia was assessed using the Misophonia Assessment Questionnaire (MAQ) (Dozier, 2015). MAQ consisted of 21 items evaluated based on 4-point scaling: 0 indicates not at all, one indicates occasionally, two indicates frequently, and three indicates nearly always. MAQ questionnaire was circulated to the participants in the form of Google Forms, and data was collected for each participant. Individual scores were summed, and participants were categorized according to the total score obtained. Scores ranging from 1-21 were mild, 22-42 moderate, and 43-63 severe. Participants categorized under mild, moderate, and severe were considered in the comparison group. Khalfa questionnaire (Khalfa, 2002) for hyperacusis was administered to rule out the presence of hyperacusis. The questionnaire has a total of 14 questions, and scoring was done through a 4-point rating scale where 0 indicates 'No', one indicates 'yes, a little', 2 indicates 'yes, quite a lot', and 3 indicates 'yes, a lot.' Scores above 28 are considered to have strong auditory hypersensitivity and patients having scores above 28 were not considered for the study. Also, the Generalized Anxiety Disorder Scale (GAD-7) was administered to rule out psychological factors (Spitzer et al., 2006). It consists of 7 questions with a 4-point rating scale where 0 indicates 'not at all', 1 indicates 'several days', 2 indicates 'more than half the days,' and 3 indicates 'nearly every day'. Scores range from 0-4 for minimal anxiety, 5-9 for mild anxiety, 10-14 for moderate anxiety, and greater than 15 for severe anxiety. Subjects having scores greater than five were not considered for the study.

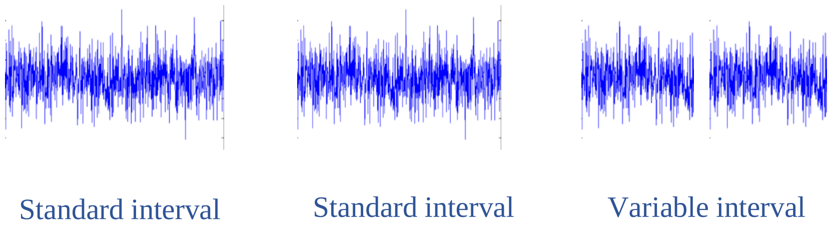
The temporal tests were administered using MATLAB software through calibrated supraural headphones (Sennheiser HD206) and using psychoacoustic toolbox. The tests were administered in a sound-treated room. The detailed procedure for the temporal processing tests is as follows:

3.5.2 Gap Detection Test (GDT)

GDT measures the shortest duration of a silent gap embedded, which can be perceived in white noise. The stimulus used was a 750 ms white noise presented to both ears at 60 dB SPL. The noise has 0.5 ms cosine ramps at the beginning and end of the ramps. A total of 30 trials were given, and one block was used in the test. Three- alternate forced choice method was used from which the participant identified the sound that had the gap as shown in Figure 3.1. Stimuli with varying gap durations were presented. The initial gap duration given was 10 ms, and the threshold was estimated using the Maximum likelihood procedure (MLP). The psychometric criterion used was 0.72.

Figure 3.1

Representation of stimuli used for Gap detection test.

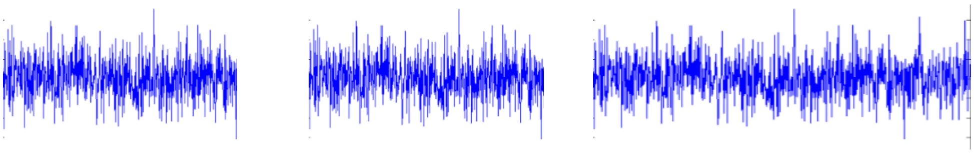


3.5.3 Duration discrimination threshold (DDT)

A sequence of three tones was presented with two tones having the same duration and one having a different duration, as shown in Figure 3.2. The participant was required to report which of the three tones had a longer interval. The standard tone duration used was 250 ms, and the noise had raised cosine onset and offset gates of 10 ms. The stimuli were presented at 60 dB SPL, and the psychometric criterion used was 0.8. A total of 30 trials were given, and the test had one block. Three alternate forced choice methods were used, and the duration discrimination threshold was determined using the Maximum likelihood procedure (MLP).

Figure 3.2

Representation of stimuli used for Duration discrimination test

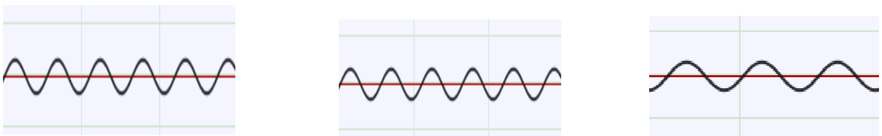


3.5.4 Pitch Pattern Test (PPT)

The recorded audio sample by Shivani and Vanaja (2003) was played using a Windows media player. It consists of two frequencies- high (1122 Hz) and low (880 Hz) which were presented in triplets where each tone duration was 200 ms (180 ms plateau, rise/decay time of 10 ms), as shown in Figure 3.3. A total of 30 stimuli were presented binaurally at 60 dB SPL. The inter-tone interval used was 200 ms, and each triplet was a pseudo-random combination of high and low tones (e.g., high-low-low). The participant repeated the tone pattern in both verbal and humming conditions, and PPT scores were recorded for both conditions.

Figure 3.3

Representation of stimuli used for Pitch pattern test

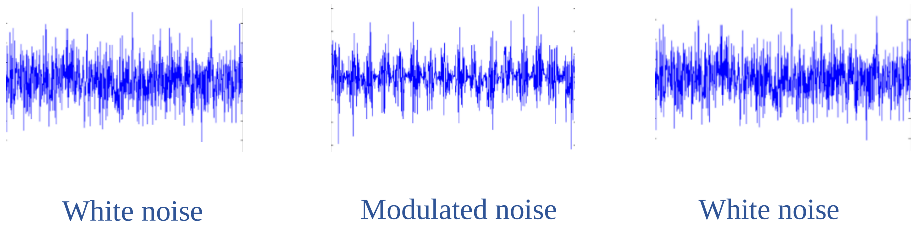


3.5.5 Temporal Modulation Transfer Function (TMTF)

The participants were presented with three tones in which two tones were unmodulated, and one tone was modulated. They were required to detect the modulated tone among the three-tone sequences. The stimuli used were a Gaussian noise burst of 500 ms duration with two 10 ms raised cosine ramps at onset and offset which were presented at 60 dB SPL. The depth of the modulation was expressed as 20 log(m), where m is the modulation index that ranges from 0.0 (no modulation) to 1.0 (full modulation). The modulation frequencies used were 8 Hz, 20 Hz, 60 Hz, and 200 Hz. A total of 30 trials were given in three alternate forced-choice methods. The TMTF threshold was determined for all the modulation frequencies using the Maximum likelihood procedure (MLP), and the psychometric criterion used was 0.72.

Figure 3.4

Representation of stimuli used for Temporal modulation transfer function



Statistical Analyses

Statistical analyses of the collected data were performed using IBM Statistical Package for Social Sciences (SPSS) version 25.0 (SPSS Inc., Chicago). Shapiro-Wilk test of normality was performed to verify whether data were distributed normally. Inferential statistics were carried out to check for the presence of significant differences between the control and experimental groups. For parametric data, an Independent t-test was done, and for non-parametric data, Mann Whitney U-test was done. To check within-group differences for the Frequency pattern test- verbal and humming conditions, the Wilcoxon Signed Rank test was carried out. Spearman's correlation (ρ) test was computed to evaluate the relationship between misophonia severity and the misophonia individuals' performance in all the temporal tests.

CHAPTER 4

RESULTS

This study examined the differences in temporal auditory processing between normal-hearing individuals with and without misophonia. The study also investigated the correlation between the severity of misophonia and the performance of misophonia individuals in all the temporal processing tests.

4.1 Gap detection test

Descriptive statistics were used to summarize and describe the main features of the dataset, such as mean, median, standard deviation, and range, as shown in Table 4.1.

Table 4.1

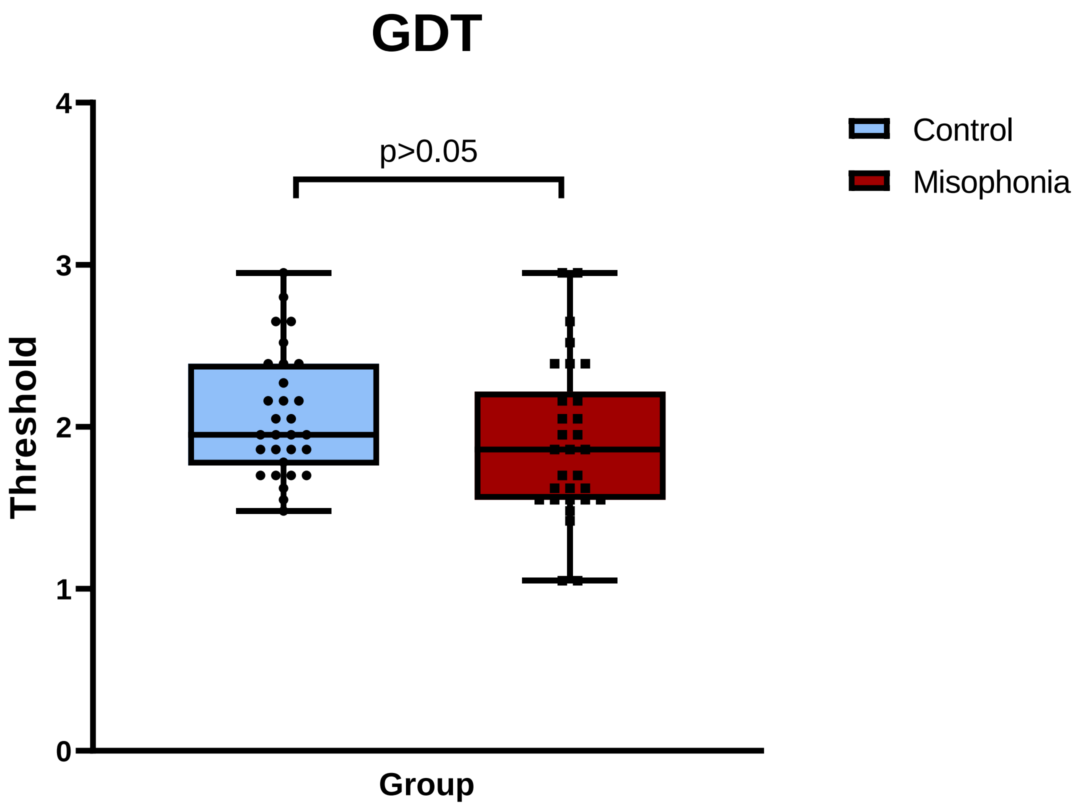
Descriptive statistics of gap detection threshold for control and misophonia group

	Mean	Median	Std. Deviation	Minimum	Maximum
Control	2.06	1.95	0.38	1.48	2.95
Misophonia	1.9	1.86	0.48	1.05	2.95

Shapiro Wilk test was done to check whether the data is normally distributed. The data was found to be normally distributed ($p > 0.05$), and an appropriate parametric test was chosen for further statistical analysis. Independent t-test was performed to check for significant differences between the control and experimental group. The result showed [$t(58)=1.45$, $p > 0.05$], which indicates no statistically significant difference between the groups. The mean and standard deviation for both groups are shown in Figure 4.1.

Figure 4.1

Mean and standard deviation of gap detection thresholds for control and misophonia group



4.2 Duration Discrimination test

The data were subjected to descriptive statistics analysis, and the mean, median, standard deviation, and range are in Table 4.2.

Table 4.2

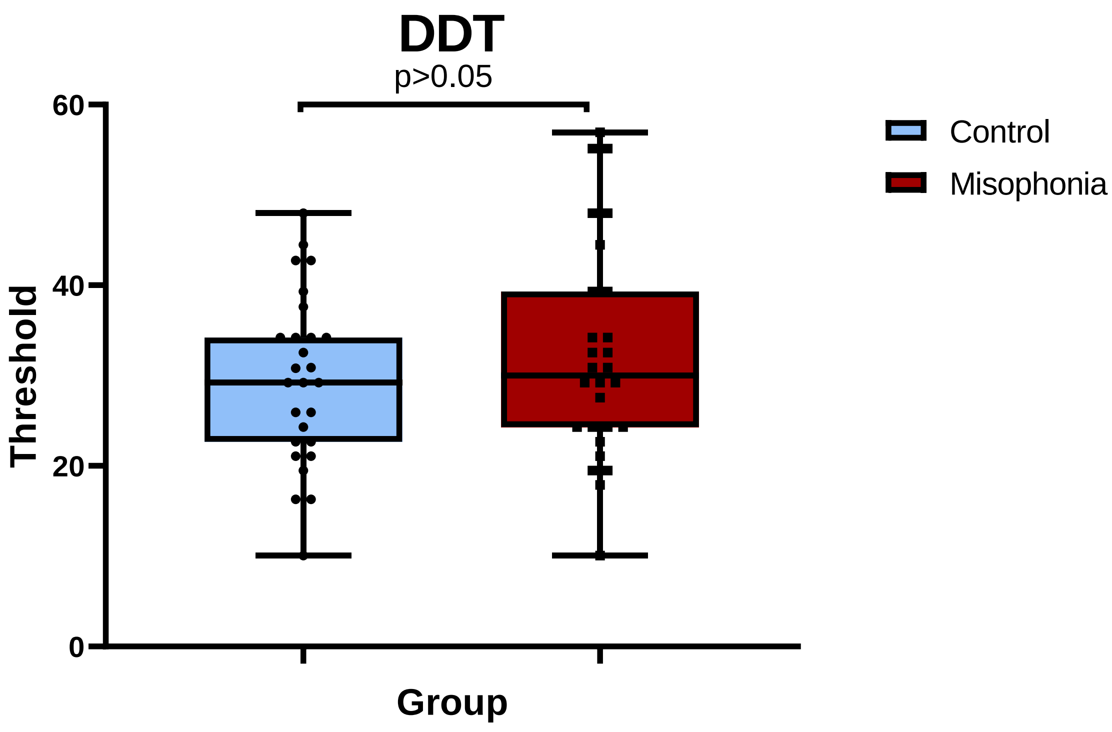
Descriptive statistics of duration discrimination threshold for control and misophonia group.

	Mean	Median	Std. Deviation	Minimum	Maximum
Control	35.83	30.83	22.79	10.08	129.84
Misophonia	32.3	30.04	12.1	10.08	56.94

Shapiro's Wilk test was administered to check for normality, and the data was found to be not normally distributed. An adequate non-parametric test was selected for statistical analysis. Hence, Mann-Whitney U test was administered to check for significant differences between the control and misophonia groups. The result showedno statistically significant difference [/Z/= 0.13, $p > 0.05$] between the groups. The mean and standard deviation for this test are shown in Figure 4.2.

Figure 4.2

Mean and standard deviation of duration discrimination thresholds for control and misophonia group.



4.3 Temporal Modulation Transfer Function

Descriptive analyses were conducted, and the mean, median, standard deviation and range for the data are shown in Table 4.3.

Table 4.3

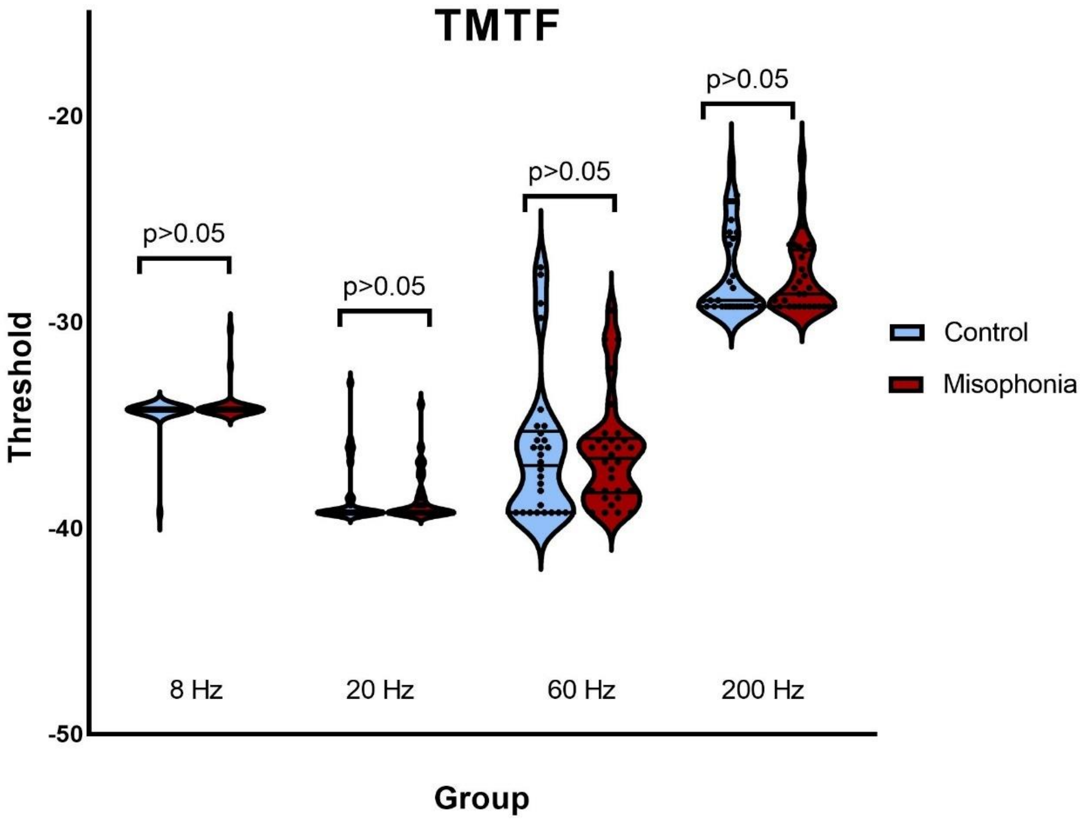
Descriptive statistics of Temporal modulation transfer function for control and misophonia group.

Frequency modulation	Group	Mean	Median	Std. Deviation	Minimum	Maximum
8 Hz	Control	-34.41	-34.25	0.91	-39.25	-34.25
	Misophonia	-34.05	-34.25	0.79	-34.25	-30.35
20 Hz	Control	-38.48	-39.25	1.54	-39.25	-32.95
	Misophonia	-38.56	-39.25	1.24	-39.25	-34
60 Hz	Control	-36.29	-36.97	3.51	-39.25	-27.35
	Misophonia	-36.34	-36.62	2.62	-39.25	-29.45
200 Hz	Control	-27.75	-28.95	2.11	-29.25	-22.35
	Misophonia	-27.86	-28.65	3.49	-39.25	-16.35

Shapiro-Wilk test was done to assess for normality, and the data were not normally distributed. Mann Whitney U test was administered, and the results indicated no statistically significant difference in the TMTF thresholds [TMTF 8 Hz: /Z/= 1.72, $p > 0.05$; TMTF 20 Hz: /Z/= 0.46, $p > 0.05$; TMTF 60 Hz: /Z/= 0.54, $p > 0.05$; TMTF 200 Hz: /Z/= 0.20, $p > 0.05$] between the groups at all the carrier frequencies. The mean and standard deviation for all the frequency modulation conditions are shown in Figure 4.3.

Figure 4.3

Mean and standard deviation for temporal modulation transfer function thresholds for control and misophonia.



4.4 Frequency pattern test

Descriptive statistics were performed, and the data for mean, median, standard deviation, and range are given in Table 4.4.

Table 4.4

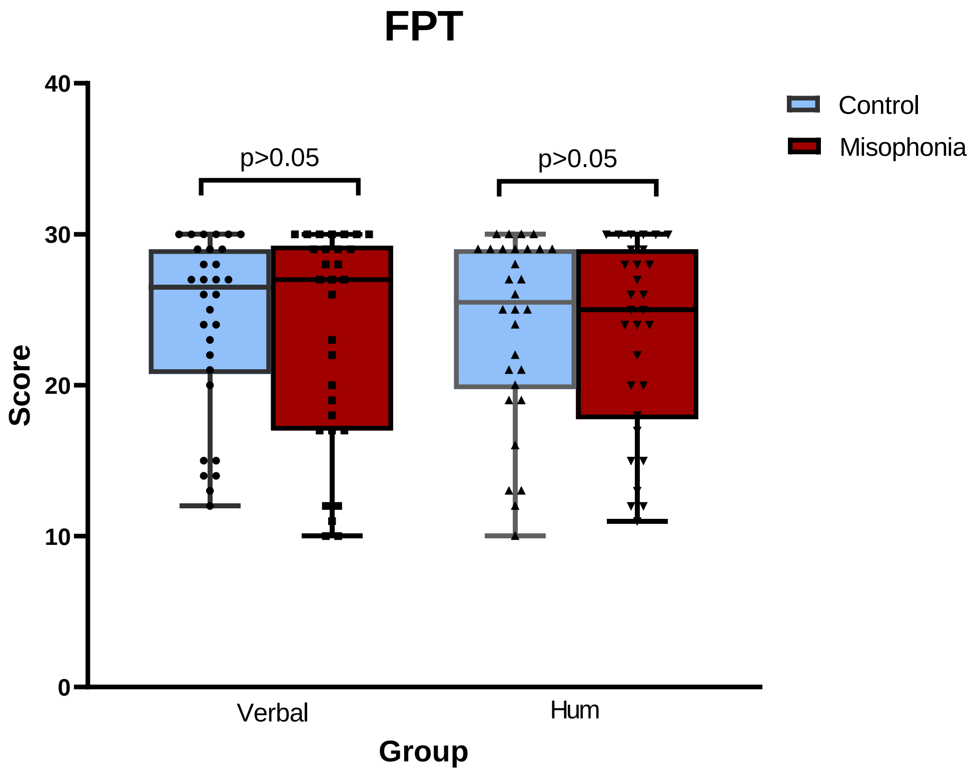
Descriptive statistics of Frequency pattern test for control and misophonia.

Condition	Group	Mean	Median	Std. Deviation	Minimum	Maximum
Verbal	Control	24.17	26.5	5.94	12	30
	Misophonia	23.23	27	7.13	10	30
Hum	Control	23.87	25.5	6.14	10	30
	Misophonia	23.27	25	6.37	11	30

Shapiro Wilk's test of normality was performed and the data was found to be not normally distributed. Mann Whitney U test was administered to examine for significant differences between the groups. For the verbal condition, the results showed that /Z/= 0.15, $p > 0.05$ and for the hum condition, it showed /Z/= 0.31, $p > 0.05$. Both results indicated no statistically significant difference between the control and misophonia groups. The mean and standard deviation for both groups in verbal and humming conditions are shown in Figure 4.4.

Figure 4.4

Mean and standard deviation for Frequency pattern test in verbal and hum conditions for control and misophonia.



Also, the Wilcoxon signed rank test was administered to examine any significant difference between verbal and humming conditions within the misophonia group. The results showed /Z/= 0.39, $p > 0.05$, which represented no statistically significant difference between both conditions.

4.5 Correlation between severity and performance of misophonia individuals

The study also attempted to examine the correlation between the performance of misophonia individuals in various temporal auditory processing tests and the misophonia severity. Since the study has only individuals with mild and moderate severity, the test scores were correlated with the same. Spearman's correlation test was administered, and it showed no significant correlation in all the tests. The results of the correlation test are shown in Table 4.5.

Table 4.5

Correlation between severity of misophonia and temporal processing test scores.

MAQ	*Rho* ρ	Sig. (2-tailed)
GDT	0.05	0.76
DDT	0.09	0.81
TMTF 8 Hz	0.07	0.71
TMTF 20 Hz	0.03	0.86
TMTF 60 Hz	0.04	0.80
TMTF 200 Hz	0.06	0.75
FPT-verbal	0.08	0.67
FPT-hum	0.04	0.82

The test of normality, Shapiro's Wilk test was administered to check for normality. The test data were not normally distributed for the Duration discrimination test, Temporal modulation transfer function, or Frequency pattern test, and data were normally distributed for the Gap detection test. Hence, for the gap detection test, the Independent t-test was used, and for all other tests Mann-Whitney U test was used. The test results showed no statistically significant difference between the control and misophonia groups.

Hence, overall, there is no significant difference in temporal auditory processing between the two groups. Also, there is no correlation between the severity of misophonia and the temporal processing test scores.

CHAPTER 5

DISCUSSION

The results from all four temporal tests (GDT, DDN, TMTF, and FPT) indicated that temporal processing is unaffected in individuals with misophonia, which demonstrates that temporal resolution, temporal discrimination, and temporal ordering processes are normal. This study's results are also on par with the results obtained by Ila et al. (2023). The latter study focused on measuring temporal processing through the gap in noise test, duration pattern test, and frequency pattern test. In contrast, this study measured temporal processing through the gap detection test, duration discrimination test, temporal modulation transfer function test, and frequency pattern test. The statistical analysis showed no significant difference in all four temporal processing tests and no significant correlation between the severity of misophonia and the performance in all temporal processing tests.

Studies show that no peripheral impairments are reported in individuals with misophonia (Aazh et al., 2022; Edelstein et al., 2013). The fMRI studies showed hyperactivation of the right insula, right anterior cingulate cortex, right superior temporal cortex, and anterior insular cortex (Eijsker et al., 2019; Kumar et al., 2017) Also, there is evidence for stronger mirroring neurons in individuals with misophonia compared to the control group, and this is stronger and specific to trigger sounds (Kumar et al., 2021) All these studies indicate abnormalities in misophonia at the cortical level. However, this study indicates no abnormalities in temporal processing behaviorally, which is also supported by Ila et al. (2023). This study evaluated only 30 misophonia individuals of mild and moderate severity. This signifies that misophonia individuals with mild and moderate severity have normal temporal processing. More studies on higher degrees of severity and a larger number of participants can be considered for future studies. All the tests performed in this study were done in a quiet environment, which is optimal for listening. Further studies could be done in misophonia, where these tests are performed in adverse listening conditions, such as with lower signal-to-noise ratios, in the presence of different types of noises, etc. Auditory brainstem response findings demonstrated normal ABR parameters, indicating retro-cochlear processing up to the brainstem regions is unaffected (Aryal & Prabhu, 2023).

Tinnitus and hyperacusis are conditions similar to misophonia, and there are reports of abnormal temporal processing in these conditions. In a study by Raj-Koziak et al. (2022), GDT scores were poorer than the control group, whereas FPT and DPT did not have significant differences. This shows that temporal resolution is affected in the tinnitus group, unlike temporal ordering, even though both come under temporal auditory processing. Temporal resolution is more crucial than temporal ordering for the correct perception of phonemes, syllables, and words; hence, temporal resolution is more closely related to speech intelligibility (Raj-Koziak et al., 2022) There are numerous studies that demonstrate abnormal gap in noise test performance in tinnitus individuals (Fournier & Hébert, 2013; Gilani et al., 2013; Jain & Sahoo, 2014; Sanches et al., 2010; Turner et al., 2006) There was no significant correlation between the severity of tinnitus and the performance in the gap detection test (Jain & Sahoo, 2014) Few studies show contradicting results, i.e., gap detection ability is unaffected in tinnitus individuals (An et al., 2014; Boyen et al., 2015) Duration pattern test scores are unaffected in the tinnitus group (Gilani et al., 2013; Raj-

Koziak et al., 2022) Due to the Duration Pattern Test's insensitivity to structural anomalies below the auditory cortex, the results in tinnitus individuals were normal. However, the gap detection mostly depends on processes within or peripheral to the brainstem (Gilani et al., 2013). Tinnitus location also affects temporal processing differently. Unilateral and bilateral tinnitus have different sites of generation (Vanneste et al., 2011; Vasama et al., 1998) Superior premotor cortex activity is elevated for unilateral tinnitus compared to control participants, whereas ventral prefrontal cortex, frontopolar cortex, and superior premotor cortex activity are elevated for bilateral tinnitus compared to control patients (Vanneste et al., 2011) The bilateral tinnitus group had poorer scores than the unilateral group (Jain & Dwarkanath, 2016). Tinnitus and hyperacusis share a common underlying pathophysiology, and studies on hyperacusis depict abnormal temporal processing abilities (Boucher et al., 2015; Salloum et al., 2016; Turner & Parrish, 2008). This indicates that the mechanism of misophonia could be different compared to tinnitus and hyperacusis. Also, the severity of misophonia is not correlated with the performance of the temporal tests, which is similar to the findings seen in tinnitus (Jain & Sahoo, 2014). Temporal processing has an important role in speech perception, and as temporal processing skills deteriorate, it may impact the person's ability to perceive speech (Kumar et al., 2012). Newman et al. (1994) reported poor speech in noise score for tinnitus individuals. The present study and the study by Ila et al. (2023) indicate that temporal processing abilities are not affected in misophonia like tinnitus and hyperacusis.

CHAPTER 6

SUMMARY AND CONCLUSIONS

Misophonia is a disorder where ordinary daily sounds impact life, causing behavioral or physiological responses. There have been studies reported where temporal processing is affected in tinnitus and hyperacusis. Since tinnitus, hyperacusis, and misophonia have similar pathophysiology, abnormal temporal processing can be expected in misophonia. This study aimed to find the same. Sixty normal-hearing individuals were considered for this study. Out of which, 30 had misophonia and were considered the experimental group, and the remaining 30 without misophonia were the control group. Misophonia Assessment Questionnaire (MAQ) was administered to determine the severity of misophonia. Khalfa Questionnaire for hyperacusis and Generalized Anxiety Disorder Scale (GAD-7) were administered to rule out hyperacusis and psychological factors, respectively. Individuals with a history of ontological complaints, noise exposure, ototoxic medications, vestibular migraine, tinnitus, hyperacusis, diabetes, hypertension, anxiety, or depression are excluded from the study. The temporal processing ability was assessed through the following four tests: Gap detection test, duration discrimination test, temporal modulation transfer function test, and frequency pattern test.

The results revealed no statistically significant difference between the performance of individuals with and without misophonia in all four temporal processing tests. This indicates that this group's temporal resolution, discrimination, and ordering are unaffected. Also, the results showed no significant correlation between the severity of misophonia and the performance in each temporal test.

6.1 Implications

- The study provided a better insight into the temporal processing skills in misophonia.
- Since temporal processing and speech intelligibility are interlinked, it can be hypothesized that speech perception is unaffected in this group.

6.2 Future directions

- A larger sample size can be considered for future studies
- The study can be performed on individuals with higher misophonia severity.
- The temporal processing tests can be administered in adverse listening conditions.

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