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Auditory Processing and Neuroregulation in Misophonia: A Comparative Study of Behavioral Measures

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Abstract

Misophonia is a condition of intolerance to certain sounds which act as triggers. This study investigates auditory processing abilities using behavioral measures in normal-hearing individuals with and without misophonia. Thirty participants aged between 18 and 30 years were included. They were divided into two primary groups: 15 individuals diagnosed with misophonia and 15 controls. All of the participants underwent auditory processing tests such as masking level difference (MLD), dichotic consonant-vowel (DCV), and pitch pattern tests (PPT). From the analyzed data, individuals with misophonia showed significantly reduced scores in DCV and PPT. Also, there was no significant difference in the thresholds of MLD at 500 Hz. This study highlights that the reduced scores of DCV and PPT in individuals with misophonia could be attributed to poor auditory cortical processing compared to the control group.

Keywords: misophonia; masking level difference; auditory processing abilities; binaural integration

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Introduction

The term *misophonia* is derived from the Greek words *misos* (meaning hate) and *phónè* (meaning sound). It is defined as a disorder wherein individuals experience reduced tolerance to specific auditory stimuli independent of the stimuli's loudness (Jastreboff & Jastreboff, 2002; Swedo et al., 2022). These stimuli, termed *triggers*, evoke an unpleasant or distressing experience associated with strong negative physiological (e.g., increased muscle tension, increased heart beat rate, sweating), emotional (e.g., anger, disgust, irritation, and anxiety) and behavioral (e.g., avoidance, escaping, and even aggression through verbal or physical outburst in extreme cases) responses, which are unexpected for such acoustic stimuli from a typically normal-hearing individual without misophonia (Swedo et al., 2022). These triggers can be specific auditory, visual, or audiovisual inputs (Aazh et al., 2019; Danesh & Aazh, 2020; Daniels et al., 2020; Jastreboff & Jastreboff, 2003, 2014). Sounds produced by humans, such as breathing, chewing, lip-smacking, and swallowing can be aversive auditory triggers (Hansen et al., 2021). Other human sounds not directly related to the human body include clicking, rustling, and typing, which can also be auditory trigger sounds (Hansen et al., 2021; Jastreboff & Jastreboff, 2003). Studies on the prevalence of misophonia have been reported among college students and the general population across various countries. Western countries vary from 4.6% to 54% (Brennan et al., 2023; Dixon et al., 2024). In India, the prevalence ranges from 15% to 34% (Aryal & Prabhu 2022; Gowda & Prabhu, 2024; Patel et al., 2022; Sujeeth et al., 2023; Yadav et al., 2024). Several neuroimaging studies have reported misophonia to have an etiology related to abnormal neural anatomy and physiological interactions between neural structures (Eijsker et al., 2021; Kumar et al., 2017, 2021; Neacsiu et al., 2022; Schröder et al., 2015, 2019). Also, the development of neurophysiological and neuroaudiological models to explain the pathophysiological process of misophonia shows a neurological basis and associates misophonia features with the cortical areas (Aryal & Prabhu, 2023c; Jastreboff & Jastreboff, 2023).

Central auditory processing is the ability of an individual to process auditory information in the central auditory nervous system (CANS). Understanding the neuroanatomy and physiology of the CANS will help us interpret its underlying processes and deficits (Bellis, 2011; Chermak & Musiek, 1997; Task Force on Central Auditory Processing Consensus Development, 1996). Auditory processing encompasses temporal processing, binaural interaction, integration, fusion, separation, and closure (Bellis, 2011; Chermak & Musiek, 1997; Task Force on Central Auditory Processing Consensus Development, 1996). Binaural integration involves the ability to simultaneously process and repeat auditory stimuli presented to both ears (Bellis, 2011). Whereas, binaural interaction refers to the brain's ability to interpret and process sounds presented simultaneously to both ears. This process occurs at the CANS level, particularly within the brainstem, where auditory information from both ears is integrated and interpreted (Bellis, 2011). Auditory temporal processing refers to the brain's ability to perceive and interpret the temporal characteristics of sound (Bellis, 2011; Chermak & Musiek, 1997). Traditionally, binaural interaction skills are evaluated using the masking level difference (MLD) test. Binaural integration abilities are measured through the dichotic consonant-vowel (DCV) test, which requires the individual to simultaneously process different consonant-vowel pairs presented to each ear and respond accordingly. Temporal processing skill is traditionally evaluated using the pitch pattern test (PPT) and duration pattern test (DPT). Alterations at the brainstem and cortical auditory processing could contribute to the heightened emotional responses to specific trigger sounds observed in misophonia.

Literature on auditory processing abilities reported no significant differences between individuals with misophonia and the control group (Ila et al., 2023; Madappally et al., 2024). However, the study by da Silva and Sanchez (2019) explored the selective attention of individuals with misophonia using dichotic listening tasks. Also, a recent study by Kim et al. (2023) reported that individuals with misophonia exhibited poor speech perception in the noise (SPIN) test at +20 and +5 signal-to-noise ratio (S/N). These results demonstrate possible poor auditory closure and binaural integration abilities in individuals with misophonia. Typically, individuals with normal hearing should be able to quickly tune out or ignore typical trigger sounds, such as chewing or sniffling, to keep their attention on more pertinent auditory information while in an environment. Nonetheless, most individuals with misophonia exhibit fixation and hyperfocus on these trigger sounds, such as chewing or sniffling, and encounter difficulty filtering out these sounds rather than background noise (Pellicori, 2020), while individuals with central auditory processing disorder (CAPD) do not appear to have autonomic nervous system arousal, which is a significant distinction between the two conditions (Pellicori, 2020). It is also reported that impaired auditory processing may have diminished N1 amplitude in individuals with misophonia (Schröder et al., 2014). However, studies by Ila et al. (2023) and Madappally et al. (2024) focused solely on individuals with mild to moderate misophonia, leaving the potential impact of more severe forms of the disorder on brainstem and cortical auditory processing unexplored. Similarly, Kim et al. (2023) did not specify the severity of misophonia in their sample. As a result, there is a possibility that variations in auditory processing may be associated with the severity of misophonia, with individuals exhibiting more severe symptoms potentially showing abnormal auditory processing at the brainstem and cortical level. Thus, it can be hypothesized that neural processing at these levels may be altered in individuals with misophonia with higher severity. Hence, the present study assesses auditory processing in individuals with moderate to severe misophonia.

Also, assessing auditory processing abilities in individuals with misophonia could provide valuable insight into atypical auditory processing patterns at the brainstem and cortical level, which may be associated with the disorder (Brout et al., 2018; Schröder et al., 2014). Hence, it would be intriguing to see the auditory processing abilities in individuals with misophonia utilizing behavioral auditory processing tests. Therefore, the current research aims to assess auditory processing abilities using behavioral measures in normal-hearing individuals with and without misophonia**.** The objective is to compare the scores of the DCV, PPT, and MLD thresholds between individuals with and without misophonia.

Materials and Methods

Participants

This research employed a standard group comparison design with purposive sampling. Thirty participants were recruited between 18 and 30 years (Mean age = 24.23, *SD* = 2.91 years). These participants were divided into two primary groups: one consisting of 15 individuals diagnosed with misophonia and the other of 15 controls (23 females and seven males). Among those in the misophonia group, 10 individuals were classified as having a moderate degree of misophonia, while five had severe misophonia. The Duke-Vanderbilt misophonia screening questionnaire was utilized to screen the participants (Williams et al., 2022). The selection of individuals with misophonia was based on the diagnostic criteria devised by Schröder et al. (2013a) and MisoQuest, as described by Siepsiak et al. (2020). The severity of misophonia was assessed using the Revised Amsterdam Misophonia Scale (RAMISO-S; Jager et al., 2020). The RAMISO-S scores were categorized as follows: 0–10 indicating no misophonia (subclinical), 11–20 indicating mild misophonia, 21–30 indicating moderate misophonia, and 31–40 indicating severe misophonia. Participants with scores of 10 or below were considered to have no misophonia, while those with scores of 21 or higher were included in the study.

The inclusion criteria for participants were as follows: no significant history of otological disorders, chronic or repeated exposure to loud noise, alcohol use, smoking, ototoxic medications, a family history of hearing loss, or any other medical conditions that could potentially influence the study outcomes. Individuals with tinnitus were excluded based on the scores of the Tinnitus Handicap Inventory (THI; Newman et al., 1996), and those with hyperacusis were excluded using the Modified Khalfa Hyperacusis Questionnaire (MKHQ; Khalfa et al., 2002). Also, those with phonophobia were excluded using the Decreased Sound Tolerance Scale-Screening (DSTS-S; Allusoglu & Aksoy, 2021).

Ethical Approval and Consent to Participate

In the current study, all of the testing procedures were accomplished using a noninvasive technique and adhered to the conditions of the institutional ethical approval committee. The institutional ethical approval committee approved the current study, AIISH Institute Review Board (IRB) Ref: SH/IRB/M.1/21/2024-25. The test procedures were clearly explained to the participants before testing. Written informed consent was taken prior to commencing the data collection.

Procedure

A comprehensive case history was obtained from each participant to screen for potential otological issues, hearing impairments, or noise exposure. Initially, participants underwent otoscopy to identify outer ear or ear canal anomalies. This was followed by a standard audiological test battery: pure tone audiometry, middle ear measures, and distortion product otoacoustic emissions (DPOAEs), all employed to assess hearing sensitivity, middle ear function, and outer hair cell function, respectively. These tests were performed in a randomized order for both ears.

Instrumentation. Tests were conducted in the acoustically treated room by the noise level standards specified by the American National Standards Institute (ANSI S3.1 1999, R2008) standards. The following calibrated equipment was utilized for this research: Inventis Piano (Inventis Padova, Italy), Grason-Stadler Tympstar Pro (Grason Stadler, Inc., MN, USA), and Otodynamics DP Echoport otoacoustic emission instrument (ILO292-USB-II, V6).

Pure-Tone Audiometry. Pure-tone audiometry was conducted to determine the hearing thresholds for air and bone conduction. Air conduction thresholds were measured at 0.25, 0.5, 1.0, 2.0, 4.0, and 8.0 kHz; while bone conduction thresholds were obtained at 0.25, 0.5, 1.0, 2.0, and 4.0 kHz, respectively. The modified Hughson-Westlake procedure, by Carhart and Jerger (1959), was utilized to ensure accurate threshold determination. Following the modified Hughson-Westlake procedure, normal hearing sensitivity was defined as a threshold of ≤15 dB HL across octave frequencies from 250 Hz to 8000 Hz for air and from 250 Hz to 4000 Hz for bone (Carhart & Jerger, 1959). The four-frequency pure-tone average (PTA) was calculated to quantify the hearing level by averaging the thresholds at 0.5, 1.0, 2.0, and 4.0 kHz (Carhart & Jerger, 1959).

Middle Ear Measures. Tympanometry was obtained with a probe tone of 226 Hz at 85 dB SPL, and acoustic reflexes were measured at 500, 1000, 2000, and 4000 Hz (Roeser et al., 2007). All participants exhibited ‘A’ type tympanograms and had present ipsi- and contralateral acoustic reflexes at 500 and 1000 Hz (Roeser et al., 2007).

Distortion Product Otoacoustic Emissions (DPOAE). DPOAEs were measured at octave and mid-octave frequencies between 1 and 6 kHz using 65/55-dB SPL stimulus levels. A S/N of +6 dB at three consecutive frequencies was used as the criterion for the presence of otoacoustic emissions (Kemp, 2007). All participants met the inclusion criteria and proceeded with auditory processing testing.

Auditory Processing Tests. Auditory processing tests were carried out for the following processes using a personal laptop coupled to the calibrated dual-channel audiometer. Testing was done at 50 dB SL (reference: speech recognition threshold). DCV was used to evaluate binaural integration, PPT to assess for temporal ordering (Bellis, 2011), and MLD to evaluate binaural interaction. The results of the auditory processing tests were tabulated for statistical analysis.

DCV Test

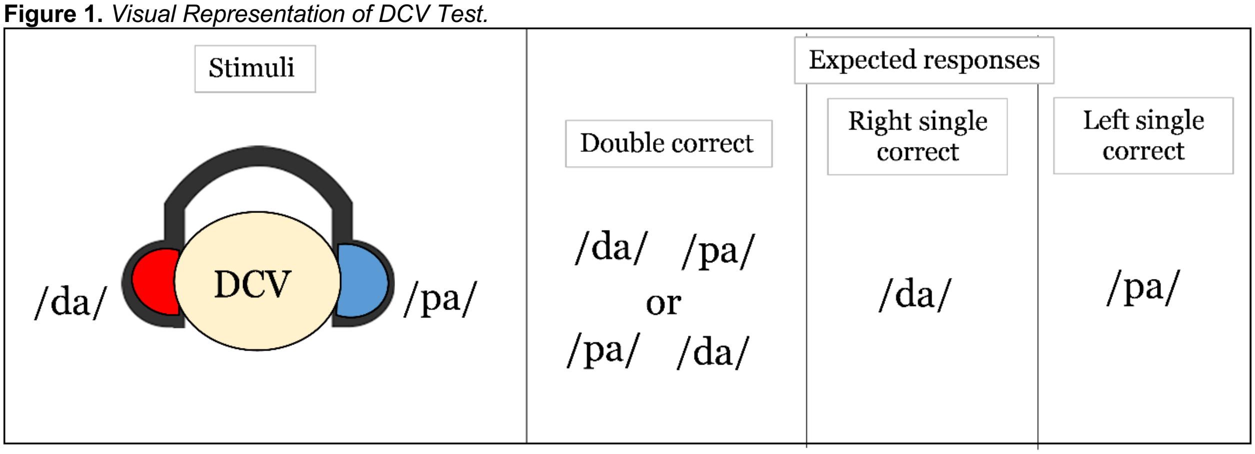
The DCV test assesses the binaural integration at the cortical level (Bellis, 2011). This test was administered using a personal laptop developed by Yathiraj (1999). Stimuli were routed through calibrated TDH 39 supra-aural headphones. The stimuli consist of six syllables (/pa/, /ba/, /ta/, /da/, ka/, /ga/), and it was randomly presented five times for 30 presentations to both ears at 50 dB SL (reference: speech recognition threshold) with a 0 ms lag between them. Before the actual testing, the participants were provided with practice items to ensure they understood the instructions.

Instructions. Instructions for DCV are as follows: *"You will be hearing two syllables – one in each ear. You need to repeat/write down both syllables regardless of the sequence."*

Scoring. For scoring, right single correct scores (RCS), left single correct scores (LCS), and double correct scores (DCS) were noted.

A visual representation of the DCV test is shown in Figure 1.

Figure 1. *Visual Representation of DCV Test.*



DCV - dichotic consonant-vowel.

Pitch Pattern Test (PPT)

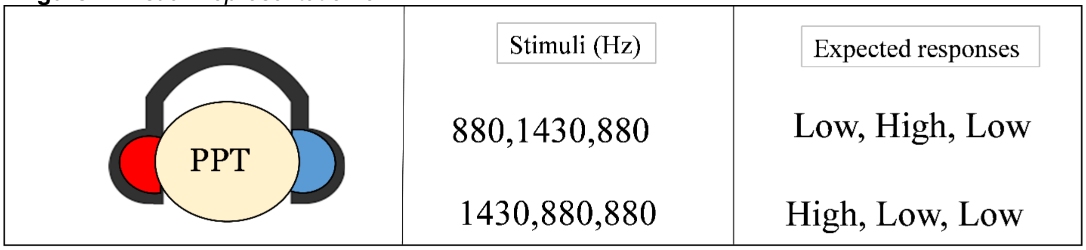
The PPT, employed to measure temporal ordering and developed by Tiwari (2003), was used to assess the cortical level (Bellis, 2011). It has six practice items in addition to 30 test items. Each item consists of three pure tones, each of 500 ms duration, separated by an interstimulus interval of 300 ms. The tone frequencies were 880 Hz (low) and 1430 Hz (high). Within each item set, two tones were similar and one was different due to the tone frequencies. The presentation level of the stimuli was at 50 dB SL. Before the actual testing, through practice items, participants were trained to distinguish between high and low tones by demonstrating the verbal tasks.

Instructions. Instructions for PPT are as follows: *"You will hear a sequence of three tones. Each tone will be either high-pitched or low-pitched. You need to repeat verbally/write down the sequences of tone, e.g., High-High-Low (HHL), Low-Low-High (LLH)."*

Scoring. Scoring was done based on the number of sequences correctly identified by the participants. If the participants responded correctly, a score of *1* for each correct response was given and *0* for every incorrect response.

A visual representation of the PPT is shown in Figure 2.

Figure 2. *Visual Representation of PPT.*



PPT - pitch pattern test.

Masking Level Difference (MLD)

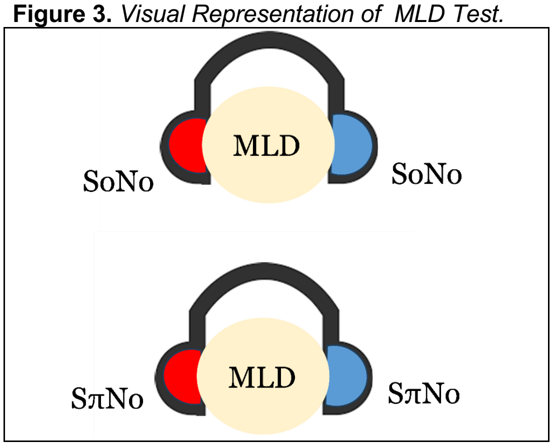
The MLD test assesses the binaural interaction at the brainstem level (Bellis, 2011). MLD was administered using a calibrated two-channel audiometer, where the signal (S) and the noise (N) were presented in homophobic (SoNo) and antiphrastic (SπNo) conditions bilaterally, and the masked thresholds were determined (Olsen et al., 1976). MLD was performed at 500 Hz with a pulse mode of 2.5 Hz, at 50 dB SL (reference: 500 Hz threshold) with 1 dB step size.

Instructions. Instructions for MLD are as follows: *"You will be hearing two stimuli (tone and noise) simultaneously in both ears; you need to pay attention and indicate when you hear the tone by raising a finger/pressing the response button given to you."*

Scoring. MLD was calculated as the difference in threshold between homophasic (SoNo) and antiphasic (SπNo) conditions (Olsen et al., 1976).

A visual representation of the MLD test is shown in Figure 3.

Figure 3. *Visual Representation of MLD Test.*



MLD - masking level difference.

Statistical Analyses

The statistical analysis was conducted using IBM SPSS Statistics (version 26, IBM Corp., Armonk, NY). The results of the Shapiro-Wilk's normality tests showed that the data were normally distributed. An independent *t*-test was done to check for any significant difference between the groups in the auditory processing abilities test scores.

Results

Comparison of DCV Scores in Individuals With and Without Misophonia

The results of the DCV test were subjected to a descriptive statistical analysis. Results show that right single correct, left single correct, and double correct scores were reduced in individuals with misophonia compared to control groups.

An independent *t*-test was conducted to determine the differences between the two groups. Independent *t*-test results showed a statistically significant difference, $t(28) = 3.64$, $p < .05$ for the right single correct score; $t(28) = 2.83$, $p < .05$ for the left single correct score; and $t(28) = 3.35$, $p < .05$ for double correct scores between the two groups.

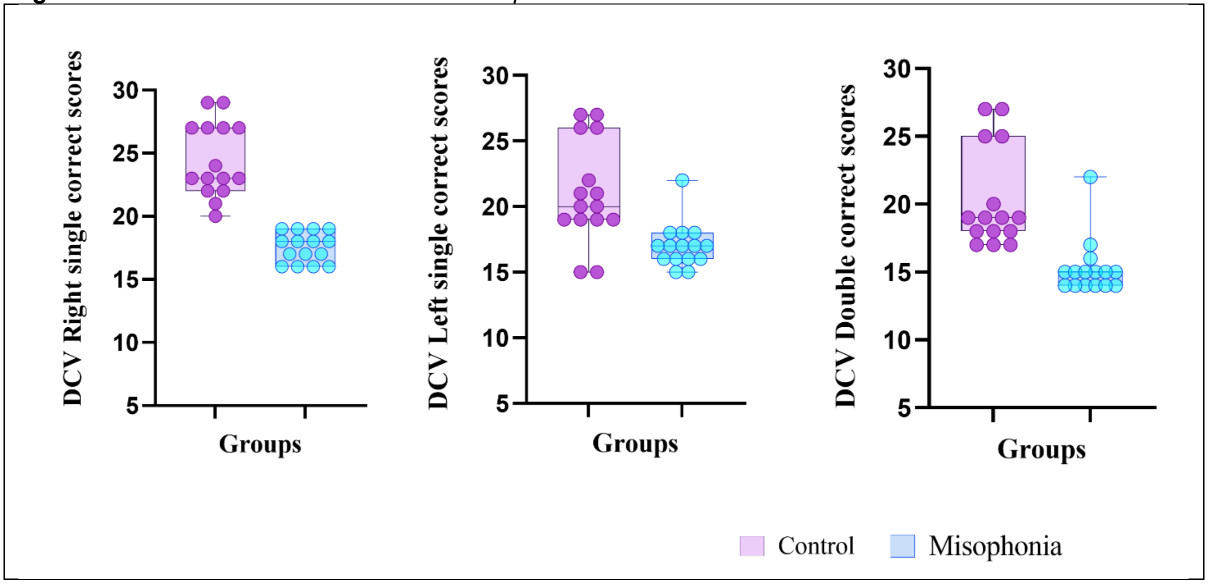
A comparison of DCV scores between the groups is provided in Figure 4.

Comparison of PPT Scores in Individuals With and Without Misophonia

The results of the PPT were subjected to a descriptive statistical analysis. Results show that PPT scores were reduced in individuals with misophonia compared to control groups.

Furthermore, an independent *t*-test was conducted to determine the differences between the two groups. Independent *t*-test results showed a statistically significant difference, $t(28) = 2.87$, $p < .05$, for PPT scores between the two groups.

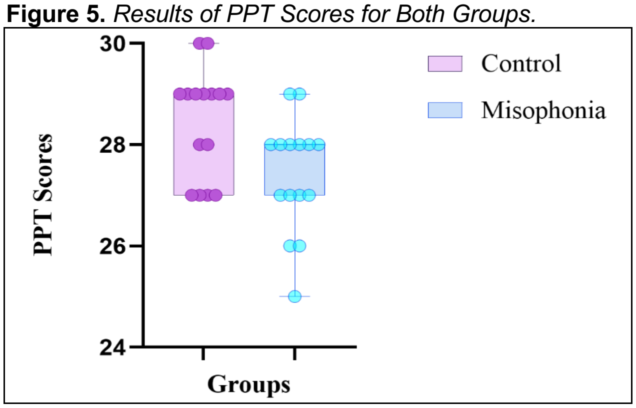
Figure 4. *Results of DCV Scores for Both Groups.*



DCV - dichotic consonant-vowel.

A comparison of PPT scores between the groups is provided in Figure 5.

Figure 5. *Results of PPT Scores for Both Groups.*



PPT - pitch pattern test.

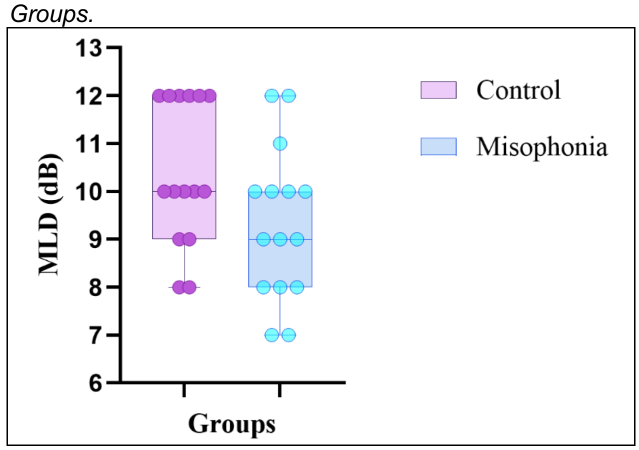
Comparison of MLD Thresholds in Individuals With and Without Misophonia

MLD results were subjected to a descriptive statistical analysis. Results show that the MLD thresholds at 500 Hz were similar between the two groups.

Furthermore, an independent *t*-test was conducted to see the differences between the two groups. Independent *t*-test results showed no statistically significant difference, $t(28) = 1.27$, $p > .05$, in MLD thresholds between the two groups.

A comparison of MLD thresholds (dB) between the groups is provided in Figure 6.

Figure 6. *Results of MLD Thresholds (dB) for Both Groups.*



MLD - masking level difference.

Discussion

The study results exhibited a significant difference between the groups in DCV and PPT, suggesting that binaural integration and temporal processing are altered. Hence, these findings indicate that individuals with higher severity of misophonia may experience disruptions in auditory processing at the cortical level. Our results are consistent with the study conducted by da Silva and Sanchez (2019), who also observed poorer scores in individuals with misophonia compared to control groups using a dichotic listening task. They proposed that individuals with misophonia might suffer from selective attention impairment (da Silva & Sanchez, 2019). This suggests that individuals with misophonia may not only exhibit heightened emotional responses to certain trigger sounds but also experience interference with their ability to process auditory stimuli effectively. The alignment between our findings and those of da Silva and Sanchez (2019) underscores the notion that individuals with misophonia may have broader deficits in selective auditory attention tasks.

These findings are further supported by Brout et al. (2018), who suggested that individuals with misophonia may have difficulty concentrating on neutral or complex sounds because their attention is drawn to trigger sounds, leading to impaired auditory processing. On the other hand, a study by Madappally et al. (2024) reported no deviations at the brainstem level utilizing a dichotic listening task. Similarly, Ila et al. (2023) found no significant difference in temporal processing tasks among individuals with misophonia. However, they stated that these results could be due to the inclusion of individuals with lesser severity (Ila et al., 2023; Madappally et al., 2024).

Neuroimaging studies, specifically those using functional magnetic resonance imaging (fMRI), have provided valuable insights into the neural mechanisms underlying misophonia. Individuals with misophonia exhibit heightened activation in brain regions associated with emotional processing, such as the anterior insula and amygdala, in response to aversive sounds (Eijsker et al., 2021; Kumar et al., 2017, 2021; Neacsiu et al., 2022; Schröder et al., 2015, 2019). This heightened emotional response may disrupt normal auditory processing pathways, leading to reduced performance on tasks like the DCV and PPT, which require focused attention on auditory stimuli without emotional interference (Schröder et al., 2013b). Furthermore, fMRI studies have suggested that individuals with misophonia may exhibit altered connectivity between the auditory cortex and regions involved in emotional regulation, which could contribute to deficits in sound discrimination (Eijsker et al., 2021; Kumar et al., 2017; Kumar et al., 2021; Neacsiu et al., 2022; Schröder et al., 2015, 2019). Rouw and Erfanian (2018) also proposed that misophonia is characterized by abnormal connectivity between these regions, potentially leading to an attentional bottleneck that could impair the ability to process auditory stimuli efficiently.

Electrophysiological evidence also indicates reduced amplitude in auditory-evoked cortical potentials in individuals with misophonia, reflecting early attentional auditory processing deficits (Aryal & Prabhu, 2023b; Schröder et al., 2013b, 2015). These findings suggest that heightened activation in the generators of auditory cortical potentials may contribute to reduced performance on auditory processing tasks. Another possible explanation is that the frontoparietal attentional networks, critical for selective attention, may be dysregulated in individuals with misophonia. Increased attention to emotionally salient sounds, such as trigger sounds, may divert cognitive resources from processing other auditory information, thereby leading to poorer scores on tasks that require binaural integration and temporal processing abilities (Cavanna & Seri, 2015; Jastreboff & Jastreboff, 2001). These findings are consistent with previous research suggesting attentional deficits in individuals with misophonia, where emotional responses overwhelm normal selective auditory processing mechanisms (Cavanna & Seri, 2015). Such results align with neurophysiological and neuroaudiological models that emphasize the role of attention in auditory perception and the processing of aversive sounds, as well as alterations in the cortical pathways in individuals with misophonia (Aryal & Prabhu, 2023c; Jastreboff & Jastreboff, 2023). Kumar et al. (2021) also observed that individuals with misophonia may have difficulty ignoring trigger sounds, which contributes to divided attention during tasks that require the simultaneous processing of multiple auditory stimuli in dichotic listening and temporal processing tests.

To the best of our knowledge, this is the first study to report deviances in auditory processing abilities within the misophonia population. Interestingly, in the present study, no significant difference was observed in the thresholds of MLD at 500 Hz, suggesting that auditory processing remains unaltered at the brainstem level in individuals with misophonia. Similarly, a study by Aryal and Prabhu (2023a) and Madappally et al. (2024) also found no abnormalities at the brainstem level. In contrast, Kim et al. (2023) observed deviances at the brainstem level by employing electrophysiological measures such as auditory brainstem response (ABR). However, in the study by Kim et al. (2023), the information on the inclusion of the severity of misophonia participants is not stated, which makes it difficult to directly compare their results with ours.

These methodological differences could be attributed to variations in outcomes regarding the relationship between misophonia and auditory processing abilities. Therefore, the findings of our study provide behavioral evidence for altered cortical auditory processing in individuals with higher severity of misophonia, resulting in poorer scores in the dichotic listening task and temporal processing tasks.

Conclusion

The current study aimed to investigate the auditory processing abilities of individuals with misophonia. Behavioral measures employed in this research indicate that individuals with a higher degree of misophonia may exhibit alterations in binaural integration and temporal ordering processes. These behavioral findings, while insightful, primarily reflect sensitivity to potential alterations in both the brainstem and cortical regions. However, to gain a more comprehensive understanding of auditory processing in misophonia, it is crucial to incorporate electrophysiological measures which would provide deeper insights into the neural mechanisms underlying these processes. Furthermore, future research examining the varying degrees of misophonia will be essential for elucidating how auditory processing abilities differ across individuals with this condition.

Implications of the Study

The findings from the present study have important implications for both the clinical understanding and management of misophonia. Firstly, the observed deviations in binaural integration and temporal processing in individuals with higher severity of misophonia suggest that auditory processing abnormalities may be more pronounced at the cortical level rather than the brainstem level. This highlights the need for future research to investigate how cortical auditory processing mechanisms contribute to the heightened emotional and attentional responses seen in individuals with misophonia.

From a clinical perspective, the identification of specific auditory processing deficits can help refine diagnostic criteria and therapeutic interventions for individuals with misophonia. For example, clinicians may consider incorporating auditory processing assessments into the diagnostic process to better understand the underlying neural mechanisms and tailor treatment strategies accordingly. Moreover, the results of this study stress the importance of considering the severity of misophonia in future research. As demonstrated by previous studies, auditory processing abilities may vary significantly depending on the degree of misophonia. This variability suggests that interventions aimed at improving auditory processing may need to be individualized, with varying approaches based on the severity and specific characteristics of each case.

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Author Disclosure

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