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Perseveration in Misophonia: A Neuropsychological Approach

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Abstract

Misophonia is categorized by strong, negative reactions to auditory stimuli, often orofacial (e.g., chewing, throat clearing), which may significantly impact daily functioning. Research on how misophonia may affect cognitive functions remains limited, though it shares characteristics with conditions known to influence cognition (e.g., Autism Spectrum Disorder, Obsessive-Compulsive Disorder). Of particular interest, those who have these disorders may display perseverance, the repetition of an inappropriate behavior rather than adapting to new stimuli. Given the similarities between these disorders and evidence of behavioral rigidity in previous studies, perseveration may also be present in misophonia. Perseveration has typically been assessed using the Wisconsin Card Sorting Test, a visual task. The current study tested perseveration and behavioral rigidity through an auditory learning task to target the sensory domain implicated in misophonia. Students from the University of Oklahoma participated by completing a detailed online survey that gauges experiences and severity of misophonia, followed by an audiology workup, then battery of behavioral tasks while Electroencephalography (EEG) data was collected to correlate behavioral outcomes with neural markers of auditory sensory fidelity. While this study did not replicate behavioral rigidity, and neural markers did not correlate with behavioral measures as anticipated, one neural marker showed a relationship with a perseverative measure. Although explicit perseveration was not observed, correlations between perseverative and behavioral measures warrant the need for further investigation. This work may provide insight into the cognitive factors that influence misophonia.

Background

Misophonia, the "hatred of sounds" (M. M. Jastreboff & Jastreboff, 2002), is described as a decreased tolerance to specific auditory stimuli, also known as triggers (Ferrer-Torres & Giménez-Llort, 2022; Jager et al., 2020; Norris et al., 2022). Triggers may differ for people impacted by the condition; however, they fall into two broad categories: organic (e.g., breathing, chewing) and inorganic (e.g., typing on a keyboard, construction) sounds. It is neurophysiological and behavioral in nature. It is characterized by having strong, negative emotional and physical reactions; the main reported response to triggering sounds is anger, with some people admitting physical aggression towards objects. People with misophonia may feel anxiety at the anticipation of hearing a triggering sound (Ferrer-Torres & Giménez-Llort, 2022). They have reported avoiding situations and environments where they believe they might encounter misophonic triggers, such as missing family events, avoiding restaurants or movie theaters leading to impairment of social functioning and quality of life (Abramovitch et al., 2024; Ferrer-Torres & Giménez-Llort, 2022; Schröder et al., 2013; Wu et al., 2014). So far, the limited research in cognition in misophonia does not show evidence of impairments in general cognitive functioning when there is no trigger-related provocation (Daniels et al., 2020; Eijsker et al., 2019). The rate of occurrence in the general population is estimated to be about 3%; however, the estimated range can be as large as 6%, when counting the most severe cases, to 24% (Abramovitch et al., 2024; Andermane et al., 2023; Ferrer-Torres & Giménez-Llort, 2022; Norris et al., 2022; Wu et al., 2014). This is in part due to a lack of clear diagnostic criteria for misophonia. Research regarding causes and biological factors in misophonia is relatively sparse, limiting current understanding on what mechanisms drive the behaviors seen in the disorder.

Co-occurring conditions

There are physiological and psychological conditions that sometimes co-occur with misophonia. Due to the auditory nature of the disorder, it is seen as a co-occurring condition with tinnitus and hyperacusis, though it can be difficult to differentiate between those who have any of these disorders alone or any combination between the three (Palumbo et al., 2018). Tinnitus refers to a condition where there is a perception of a sound that does not have an external source and is most commonly described as ringing or buzzing sounds. This may potentially impact the quality of life for those who experience it. Some people may experience tinnitus due to an internally generated stimulus that stems from physiology, also known as objective tinnitus. Others may perceive a sound that has no identifiable acoustic source, externally or internally. This is known as subjective tinnitus (Atik, 2014; Norris et al., 2022). Misophonia may occur in approximately 10-60% of those who experience some form of tinnitus (Wu et al., 2014). It is still unclear whether experiences of tinnitus lead to misophonia or if they are co-occurring conditions with overlapping pathophysiology.

Hyperacusis and misophonia are both considered conditions of decreased sound tolerance. Hyperacusis refers to a lower tolerance to certain frequencies and volume ranges of sounds that would not be considered loud to others (Palumbo et al., 2018). The responses that come from hyperacusis tend to be driven by the perceived “loudness” of a sound (Raj-Koziak et al., 2021). The research suggests that people with misophonia have normal hearing sensitivities (Palumbo et al., 2018; Schröder et al., 2014). The behavioral reactions caused by misophonia and hyperacusis may be identical, making it difficult to identify the condition this way. Significant levels of hyperacusis will result in misophonia due to the discomfort of the sound. Once the association is made, the misophonic response may persist even after the hyperacusis itself decreases (P. J. Jastreboff & Jastreboff, 2015).

While the formalized diagnostic criteria are still under debate and have yet to be added to the Diagnostic and Statistical Manual of Mental Disorders (DSM 5), symptoms of misophonia co-occur with a variety of DSM diagnoses. Misophonia is associated with elevated levels of stress and anxiety that is produced by the triggers (Jager et al., 2020; Ward et al., 2022). These types of anxiety-related responses can be found in mood disorders, anxiety disorders, and obsessive compulsive-related disorders (Wu et al., 2014). It is important to distinguish between misophonia and phonophobia. Phonophobia refers to the fear of certain sounds. It may not be necessarily true that the same classes of sounds elicit a reaction in phonophobia. The main differentiation between the two is that phonophobia elicits a fear response to the triggering sounds, while misophonic triggers elicit anger (M. M. Jastreboff & Jastreboff, 2001; Palumbo et al., 2018; Schröder et al., 2013). While there are many shared behaviors between these disorders and misophonia, the common differentiation between them tends to be the reaction that is elicited. For the fear and anxiety-related disorders mentioned, the fear and/or anxiety is the perceived emotion. Anxiety may mediate the relationship between the misophonic symptoms and rage; however, the most common reaction is anger which differentiates misophonia from other fear and anxiety-related disorders (Schröder et al., 2013; Wu et al., 2014).

Misophonia, which by definition contains sensory components, also shows links to sensory processing impairment, which is symptomatic of autism spectrum disorder (ASD), schizophrenia (Norris et al., 2022), and attention deficit hyperactivity disorder (ADHD; Ghanizadeh, 2011). Misophonia is linked to having general sensory sensitivities. One study measured general sensory defensiveness using the Sensory Profile (Kinnealey & Oliver, 2002), which covered sensitivities spanning olfactory, auditory, tactile, visual and gustatory (Wu et al., 2014). General sensory defensiveness is defined as a condition where individuals display heighted aversive reactions to sensory stimuli (Kinnealey et al., 1995). There was a strong association between the misophonia symptoms (as measured by the Misophonia Questionnaire; Wu et al., 2014) and general sensory sensitivities. General sensory defensiveness may be elevated from experiencing auditory sensory processing sensitivity (Wu et al., 2014). Additionally, general sensitivities may develop early in misophonia. Sensory sensitivities seem to be heighted in adolescents with misophonia as compared to children of the same age group without misophonia. These sensitivities include all of those tested in the Sensory Profile as well as vestibular. Specifically, children with misophonia display heightened sensitivity across all sensitivity types compared to their peers (Rinaldi et al., 2023). The auditory sensitivity in ASD or sensory processing disorders comes from unexpected and loud noises, whereas misophonic responses seem to be triggered by the same sounds, so much so that misophonic triggers can be predictable and avoidable (Schröder et al., 2013). Further, people with misophonia may react to visual stimuli that are related to a triggering sound as if they heard the sound itself. For example, those who find the sound of chewing to be triggering may have an aversive response to the sight of someone chewing, though they may not hear the sound of chewing (Ferrer-Torres & Giménez-Llort, 2022).

Cognitive Behavioral Findings in Misophonia

Due to overlap with co-occurring conditions that impact cognition, such as ASD, research has explored how different areas of cognition may be impacted by misophonia which may lead to its associated behaviors. It has been suggested that misophonia is more than just the physical perception of sound; rather, it is a relationship that is mediated by high-level cognitive associations (Cerliani & Rouw, 2020). When testing for differences in cognition, it is important to make the distinction between 'cold' functioning (e.g., testing in emotionally neutral environments) and 'hot' functioning (e.g., using environments or stimuli that elicit the intended emotions; Abramovitch et al., 2024). Many areas of cognition seem to be largely unaffected by misophonia, specifically under 'cold' conditions. One study tested a large battery of cognitive functioning under 'cold' misophonia conditions, including set shifting, planning, working memory, verbal fluency, verbal memory, response inhibition, non-verbal memory, processing speed, attention, and visuospatial functioning. None of the areas of functioning indicated a strong difference in performance between the group with misophonia and the control group (Abramovitch et al., 2024). Eijester et al. (2019) aimed to test response inhibitory behaviors in people with misophonia through a Stop Signal Task without provoking misophonic reactions. They found that people with misophonia did not show impairments in their response inhibition compared to the control group (Eijsker et al., 2019). They did however display a response bias; this is discussed further later in this paper. Of note, the response bias does require more cognitive control from patients with misophonia; they exert more attentional resources to successfully inhibit responses (Eijsker et al., 2019).

Declines in cognitive functioning seem to be more prominent under 'hot' conditions. One study utilized recordings of the sounds that were rated as the most aversive (per Edelstein et al., 2013) by people with misophonia in order to elicit these 'hot' conditions (Frank et al., 2020). They played these sounds for 15 second intervals while participants were completing an attentional task. Reaching and maintaining alertness was found to be more difficult in this environment (Frank et al., 2020). To test whether cognitive functioning declined specifically as a result of misophonia triggers, Daniels et al. (2020) alternated between misophonia trigger sounds and universally annoying sounds (e.g., baby crying, person screaming, etc.). Participants completed the Stroop task as a measure of cognitive control. Emotional behaviors toward trigger sounds elicited a greater Stroop effect only when misophonia trigger sounds were played for those who experience misophonia. This result was not found when generally annoying sounds were played (Daniels et al., 2020). Cognitive control tends to be diminished in symptom provoking environments for participants who have misophonia, even after controlling for neuroticism (Daniels et al., 2020).

Some research has considered whether misophonia is a learned condition. Some have considered that misophonic triggers have the role of the conditioned stimulus, which elicits a physical muscular reflex that becomes the conditioned response (T. Dozier & Mitchell, 2023). In this model, the physical reflex drives the emotional reflex to be developed as a conditioned response along with associated physiological distress. These relationships are strengthened with exposure to triggers. The aim of this model is to identify the etiology of misophonia as a conditioned physical response (Dozier & Mitchell, 2023). Other models show that misophonia develops as an emotional reflex. Some individuals may experience negative interpersonal relationships, which is their unconditioned stimulus, and anger due to rigidity or judgment is their unconditioned response. Otherwise neutral sounds (e.g., chewing) become a conditioned stimulus when it is made by that family member and the anger becomes the conditioned response (Cowan et al., 2022). Though different models show different conditioned responses, there does seem to be some consensus that the conditioned stimulus may be a complex stimulus that involves the trigger sound and the context where the sound is heard (Dozier & Mitchell, 2023; P. Jastreboff & Jastreboff, 2014). The associations become stronger with more exposure to trigger sounds; the responses may also be explained further through perseveration.

Perseveration

Perseveration is defined as the repetition of a behavior, often one that was previously rewarded, instead of flexibly changing behaviors appropriately when prompted. This may present itself in a variety of behaviors such as motor or verbal behaviors, or an inability to change the topic of conversation. Perseveration is involuntary; it is local in time and may consist of intrusions of previous utterances and trying to redirect it may elicit negative responses (Cohen, 1998). The repeated behavior may not serve a purpose to those who engage in it whereas other types of repeated behaviors like self-stimulation (also known as stimming) may provide a calming effect for those engaging in it. Perseverative behaviors are seen in ASD, schizophrenia, and Fragile X Syndrome (Crider, 1997; Maes et al., 2011; Martin et al., 2012). As misophonia shares traits with these disorders, exploring whether people with misophonia may also present perseverative behaviors may provide additional insight into overlapping mechanisms contributing to these disorders.

Perseveration may be linked to learning behaviors. This provides further need for exploration of perseveration in misophonia, as some research suggests that misophonia is also a learned condition. Some may use learning in order to predict and avoid painful experiences (Vlaeyen, 2015). Fear and anxiety-related disorders have been linked to classical conditioning, specifically associative learning (Palumbo et al., 2018; Ward et al., 2022). Associative learning involves two stimuli that are presented simultaneously or consecutively, which evokes a pairing of reactions (Vlaeyen, 2015). This learned behavior may help explain the strong emotional reactions seen in misophonia.This association is made through the auditory cues reaching the auditory cortex then being filtered through the amygdala (M. M. Jastreboff & Jastreboff, 2001, 2002), eliciting a strong affect, that reaches the sympathetic nervous system, provoking the response (Ward et al., 2022). Further, the basal ganglia and cingulate cortex are involved in building these associations. The basal ganglia are involved in the formation of stimuli-response associations in trial-by-trial learning. The associations made through the basal ganglia tend to be ones that are inflexible and do not generalize to environments with new choices very easily (Foerde & Shohamy, 2011). The basal ganglia are also involved in the pathways that result in perseveration. Specifically, a diminished switching functionality in the basal ganglia produces a higher likelihood that an action will be maintained for the time required to perform a selected action (Fiore et al., 2016). Those with reduced ability to switch means that they will maintain the selected action.

The cingulate cortex, specifically the anterior cingulate cortex, evaluates the response that is made in a learning situation. It may have a role in behavioral adaptation and detecting changes in the learning environment (Reed et al., 2022). As this response continues to be triggered by the auditory cues, the association between the two can become stronger. Stress has been found to be associated with the brain's reward response (P. Ethridge et al., 2020). Specifically, the hypothalamic-pituitary-adrenal axis, which is responsible for buffering effects of rewards, seems to respond to stressors by enhancing delta power in the striatum when given reward-related feedback on a sensitive measure of neural processing of rewards (P. Ethridge et al., 2020). Modulation of stress-related brain activity via repeated behaviors may be partially responsible for the feedback loop that leads to perseveration.

These learning behaviors may not be updated as the goals of the tasks change due to an inability to set shift or from behavioral rigidity. This rigidity may also present itself as response inhibition, or the ability to stop motor response when faced with new stimuli. Response inhibition failure is known as impulsivity. Impulsivity in responses may contribute to overt displays of aggression, which is a common response for individuals with misophonia when encountering a trigger sound. Ejisker et al. (2019) found that people with misophonia display a response bias while completing a Start Stop Task. In any task requiring speed and accuracy of responding, there is an inherent trade-off between the two, and individuals may adopt prioritization strategies based on task demands or their own personal response biases. People with misophonia seemed to prefer accuracy, which led them to have slower stop signal detection and non-significant reaction times compared to the control group. Systematic preference for accuracy at the group level may point to behavior inflexibility leaning towards perfectionism and intolerance towards errors.

There has been some limited research on perseverative behaviors in misophonia, which suggests that individuals with misophonia are not engaging in these behaviors more than control samples (Abramovitch et al., 2024; Frank et al., 2020; Gokovali Begenen, 2023). Researchers have used the Wisconsin Card Sorting Task (WCST) to explore these behaviors, as this task is currently the industry standard for testing perseverative behaviors. The task is a visual task that assesses executive functioning, specifically conceptualization, set shifting, and rule learning via a set of cards that must be sorted by trial and error based on their characteristics until the sorting rules are learned. Sorting rules change periodically, requiring the participant to recognize a rule shift from feedback, and flexibly change behavior to discover the new rule. The WCST demonstrates whether participants have the ability to learn and adapt to using new rules as old ones no longer serve a function (Eling et al., 2008). However, the WCST may not be an appropriate or sensitive task for people with misophonia due to its visual nature. While previous research suggests that general cognition is likely to be unimpaired in individuals with misophonia, the primarily auditory nature of the disorder suggests that behavioral impairments may be modality specific. The use of the WCST in this context may not be eliciting the correct sensory cues in order to effectively test perseveration in misophonia. This elicits the need to develop a task similar to the WCST, but tests for audiological rule learning and behavioral perseveration.

Purpose and Research Objectives

Currently, there seems to be a lack of neuropsychological research pertaining to misophonia (Abramovitch et al., 2024; Frank et al., 2020; Gokovali Begenen, 2023). In order to develop a well-rounded understanding of the disorder, and to move towards diagnostics and treatment, there would need to be clear characterization of all aspects of misophonia, including potential cognitive factors. The literature concerning auditory learning and perseveration in misophonia is sparse at best. Perseveration has been explored tangentially in a handful of studies (Abramovitch et al., 2024; Frank et al., 2020), but has yet to be explored as a main aim. Furthermore, there has yet to be a study that explores perseveration in misophonia using an auditory task. This study aimed to close this gap in the research by utilizing a learning task that is similar to the WCST, but through auditory stimuli, to examine the nature of auditory learning and perseverative behaviors in people with misophonia. The first hypothesis of this study was that people with misophonia will engage in more perseverative behaviors than the control group. It was also hypothesized that those experiencing misophonia will take additional trials in order to learn the sorting rules and exhibit behavioral rigidity.

Methods

Participants

This study design was a part of a larger project conducted at the University of Oklahoma (OU) that was a multisite cross-sectional design with three components. Sixty-seven participants aged 18 to 55 completed the observational survey and two in-person portions of the study (M = 18.96, SD = 1.12; 89% female). One person was excluded due to having a pacemaker. Another person was excluded due to the length of their session. The final participant pool included 54 participants with valid electroencephalography (EEG). Participants who had indicated experiencing misophonia had matched controls; 32% of the final participant pool had indicated experiencing misophonia. Participants were recruited via OU's psychology research pool. There was an option to provide contact information for those who chose to volunteer in the in-person sessions. Participants who completed the survey were given course credit as compensation. Those who completed the first in-person portion, an audiology workup, were compensated with a $40 gift card. Participants who completed the second in-person portion, the EEG and behavioral collection session, were compensated with a $40 gift card. Those who completed the survey and both in person sessions were compensated with 4.5 course credit and $80 worth of gift cards total.

The study was approved by the Institutional Review Board at the University of Oklahoma Health Sciences Center. Consent was given at the beginning of each portion of the study, as these sessions did not occur on the same day and participants may not have to complete all the portions of the study. Participants provided written consent prior to participating in the survey. They gave additional written contents and HIPAA authorizations prior to the audiology session and the EEG collection.

Procedure

Participants completed the Spectrum Characteristics Survey, which included a battery of questionnaires to assess sensory experiences as a part of the larger study and included demographic information. The survey was created and disseminated through Qualtrics, an online survey tool. Survey participants were given the option to provide contact information if they wanted to participate in the audiology session and EEG study. The audiology session was conducted at the University of Oklahoma Health Sciences Center under the supervision of Dr. Susanne Kimball. The session included measures of tympanometry, pure-tone thresholds, loudness discomfort levels, and minimal masking levels for those who reported subjective tinnitus. The EEG study was conducted at the University of Oklahoma Norman Campus - south research campus. The study included an auditory learning task, along with a battery of EEG tasks needed for the larger study. The tasks were counterbalanced. Participants were asked to rate their anxiety levels at the start of the EEG session using a 10-point Likert scale. Participants were asked to list any current medications. Anticonvulsants were used as exclusionary criteria. Medication information was used for assessment of potential interactions with neural metrics.

Spectrum Characteristics Survey

Misophonia Questionnaire

The Misophonia Questionnaire (MQ) is a 17-item measure of misophonia symptom presence, the emotions and behaviors that may result from the symptoms, and the severity of sound sensitivities (Wu et al., 2014). The Misophonia Symptom Scale, which is the first section of the questionnaire, measures participants' specific sounds sensitivities such as tapping, chewing, or throat sounds (e.g., "In comparison to other people, I am more sensitive to the sound of repetitive tapping.") The second section, called Misophonia Emotions and Behaviors Scale, evaluates what types of emotions and behaviors are elicited from the symptoms (e.g., "Once you are aware of the sound(s), because of the sound(s), how often do you cover your ears?"). Both sections are captured on a Likert scale ranging from 0 (*not true at all*) to 4 (*always true*) for a maximum sum Total Score of 68. The final section, called the Misophonia Severity Scale, is an adapted version of the NIMH Global Obsessive-Compulsive Scale (NIMH GOCS; Murphy et al., 1982) to capture misophonia. Participants may indicate the severity of their sound sensitivity on a scale of 1 (*minimal*) to 15 (*severe*). Responses of greater than or equal to 7 indicate clinically significant severity. This was used as inclusion criteria for participants in the misophonia group.

EEG Session

Auditory Learning Task

Participants were instructed to listen to tones that differed in pitch (1000Hz or 2000Hz), frequency of amplitude modulation (40Hz - low gamma or 80Hz - high gamma), with two volumes (50db or 75 db). Each tone was presented for two seconds, which allows for analysis of the steady state oscillation power, a basic sensory function metric. Participants were then given a two second response period where they categorized the tones into four categories by pressing one of four buttons. The categories are based on pitch and amplitude modulation frequency, with volume as a distractor to increase difficulty. The four categories are low pitch, low gamma; high pitch, low gamma; low pitch, high gamma; and high pitch, high gamma. Participants must learn how to correctly categorize the tones into each category. They are given auditory feedback ("correct" or "incorrect") one second after the button press, which is followed by a three second inter-trial interval. The task continues until participants can correctly identify each of the categories two times in a row or until ten minutes have passed. One difference between this task and the WCST is the lack of set-shifting. The same sorting rules were maintained throughout the task, in order to provide a baseline measure of auditory learning. Therefore, while basic perseverative behaviors in the face of negative feedback during the acquisition of categories can be assessed, set-shifting and perseverative behaviors following a rule switch will not be explored in the current data.

Recording and Preprocessing

EEG data were recorded on a 128-channel, saline based EEG cap (Electrical Geodesics, Inc). The electrodes were placed based on the International 10-10 system. EEG data were continuously recorded through the entire session of the EEG tasks, including the auditory learning task. EEG was sampled at 1000Hz, filtered from 0.3 to 100 Hz, and referenced to Cz. Raw data files were stored and reviewed offline through a password protected server. Bad sensors were interpolated using the spherical spline interpolation, with no more than 10% of sensors removed for bad data (a total of 12 electrodes). Data were digitally filtered with a 0.3 to 100 Hz with a 60Hz notch filter (i.e., 57 to 63Hz) with the removal of harmonics up to the Nyquist frequency of the original sample. Removal of data segments that contained large movements or electrical spiking was complete before data was submitted to independent component analysis (ICA). ICA was implemented using EEGLAB in Matlab 2021.0 software (Delorme & Makeig, 2004). The components resulting from ICA were visually examined, and any that contained primarily artifact were removed with data being re-referenced to an average reference. The components were then segmented depending on type of analysis. For the event-related potential analysis, the segments were epoched for 1250 ms (-250 to 1000 ms) for the stimuli and 1000 ms (-250 to 750 ms) around the feedback given to participants. The time-frequency analysis required the segments to be epoched for 2250 ms (-500 to 1750 ms). Any epochs that contained residual artifact exceeding an amplitude threshold of +/-120μV were automatically rejected prior to analysis.

Data Analysis

Statistical analyses were run in JASP and MATLAB. First, behavioral differences of interest were examined. Participants would reach criterion for each tone by categorizing them correctly three consecutive times. Reaching criterion is an indication whether participants learned the rules of the task and successfully executed them. A 2 (group) x 4 (category) repeated measures ANOVA was used to test the differences in reaching criterion between people with misophonia and the control group for each category. Similarly, a 2 (group) x 4 (category) repeated measures ANOVA was used to examine group differences in the amount of trials it took to reach criterion. Trials to reach criterion indicates how quickly participants learned the rules of the task. Misophonia will be considered present in a participant if they indicated a 7 or greater on the Misophonia Severity Scale on the Misophonia Questionnaire.

Lag distribution analysis (LDA) and perseveration probability analysis (PPA) were used to examine perseverating behaviors in people with misophonia (Cohen, 1998). Lag distribution analysis was used to understand the frequency of the perseverative behavior (see Figure 1). A “lag” is defined as the number of trials that separates an error response from the first instance of the same response made previously. For the purpose of this study, each lag was matched with participants’ previous responses. The observed lag distribution was compared to a randomized lag distribution to test whether errors are due to genuine perseverative behaviors rather than chance. The random distribution dataset was obtained by shuffling the stimulus-response pairs 80 times. This was done for each of the categories. Shuffling the trails preserved the stimuli-error relationship, leaving nothing but the serial order altered. The lag distribution is a decreasing function of time following a logarithmic pattern: $(1 - P)^{L-1}P$, where P is the probability of a perseverative behavior, which would be constant in the absence of perseveration, and L is the lag number. The observed lag distribution and the random distribution were compared using a χ^2 goodness-of-fit test. Generally, many errors at small lags (meaning that the behavioral response was repeated from a recent trial, regardless of whether the previous response was correct or not), may indicate perseveration.

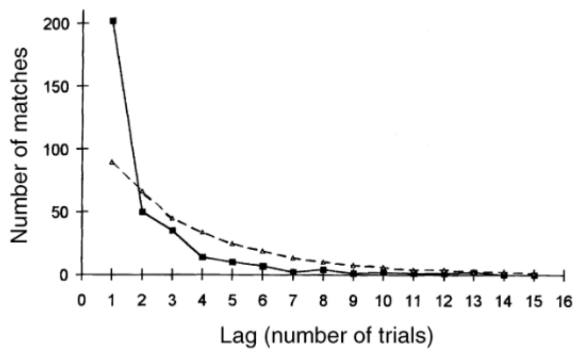
Perseveration probability analysis (PPA) was used to examine the duration of the behaviors across time (see Figure 2). Specifically, it was utilized to look at the perseverative behaviors as a series, rather than independent perseverative behaviors. This method was used to match the trials back to the preceding trials. This is also meant to correct for a conflated number of matched perseverations in the random distribution for lags other than lag 1 (Berthier et al., 2022). The random distributions from the lag distribution analysis were time corrected. This was done by using a proportion that considers each of the matched errors to previous lags. This matching does not stop at the immediate previous lag; rather, the matching continued for an arbitrary number of previous lags. The purpose of this analysis is to account for multiple matched behaviors (such as a series of repeated behaviors regardless of correctness) rather than treating each behavior independently (akin to duration vs count metrics for behavioral analyses). Previous literature has used 15 as the arbitrary number (Berthier et al., 2022; Cohen, 1998). To obtain the ratio, the matched errors, $M(L)$, are divided by the number of non-matched lags for this lag, $N(L)$. This results in the perseveration probability, $PP(L)$:

$$\frac{M(L)}{N(L) + M(L)}$$

The probability will yield a true amount of non-matched errors, instead of a falsely conflated one. Previous research had more perseveration observation trials than the current study. This, coupled with the distributions from previous studies seeming to asymptote close to zero at 10 lags (Figures 1 and 2) provided justification for reducing the number of lags counted to 10 in this study. The observed lag distribution and the time-corrected distribution of the 10 lags were compared using a χ^2 goodness-of-fit tests. Each individual's distribution shape was quantified into a single variable by computing the absolute area under the curve (AUC) between the observed and random distributions. This value was used to analyze group differences via *t*-tests and compare them to EEG variables of interest. Positive AUC specifically looked at the area of the observed distribution that is above the random distribution (e.g., lags greater than chance). This was also analyzed using a *t*-test. The absolute and positive AUC was done for the lag and the perseveration probability distributions.

Figure 1

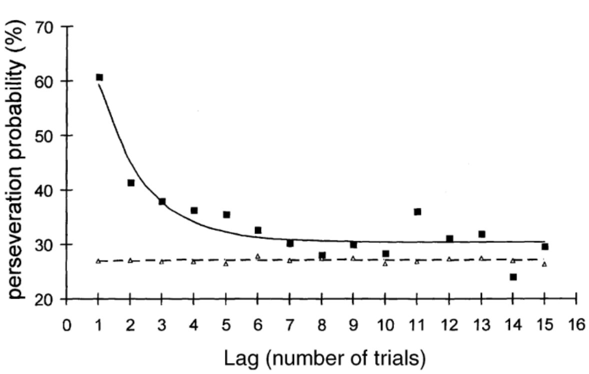
Lag distribution example



Note. Example of lag distribution over 15 trials for a participant (Cohen, 1998).

Figure 2

Example perseveration probability distribution



Note. Example of perseveration probability distribution over 15 trials for a participant (Cohen, 1998).

Relation to EEG Variables of Interest

EEG data was collected as a part of a larger study. As such, the variables that were assessed in this study were already computed. For this project, the EEG variables of interest were the stimulus onset, the 40 Hz stimulus collapsed across tone, and the 80 Hz stimulus also collapsed across tone. These variables are all measures of basic sensory processing, specifically of the auditory stimuli that were presented to participants. The purpose of assessing these variables with behavior was to explore the impact of basic sensory processing on behavior. These variables were analyzed using inter-trial coherence (ITC), which is a time-frequency measure. ITC measures the relation between oscillatory phases and whether they are 'phase-locked', measuring the similarity or the stability of the shape of the waveform across trials, to auditory stimuli across trials (L. E. Ethridge et al., 2019). It is a means to examine whether the brain, namely the auditory cortex, is tracking appropriately with a given stimulus. ITC for each of these variables was correlated with behavioral measures: trials to criterion, meeting criterion, and absolute AUCs for the lag distribution and perseveration probability distribution.

Results

A 2 (group) x 4 (category) repeated measures ANOVA was run to assess the differences in meeting criterion on each category between groups (control, misophonia). First, the assumption of equal variance between groups was analyzed using Mauchly's test of sphericity; this assumption was met, $\chi^2(5) = 9.47$, $p = 0.09$. There were no statistically significant main effects. Specifically, there was not a significant main effect of group membership, $F(1, 3) = 0.20$, $p = 0.66$. There was also no significant main effect for reaching criterion on the categories, $F(1,$

3) = 0.37, p =0.79. There was no significant interaction in meeting criterion by category across group membership, $F(1, 3) = 0.07$, $p = 0.98$ (Table 1).

Table 1

Repeated measures ANOVA table for reaching criterion.

Source	Sum of Squares	*df*	Mean Square	*F*	*p*
Between-subjects effects					
Group membership	0.058	1	0.058	0.197	0.0778
Residuals	15.313	52	0.294		
Within-subjects effects					
Category	0.248	3	0.083	0.366	0.778
Category x Group membership	0.044	3	0.015	0.065	0.978
Residuals	35.215	156	0.226		

Note. $N = 54$.

The percentage of people who met criterion was assessed for each of the categories. This was done on the entire participant pool to assess whether people were indeed meeting criterion on the categories. The category of 40 Hz amplitude modulation by 1000 Hz pitch had the most people reaching criterion, with 67% of participants reaching criterion. This is followed by 63% reaching criterion on 80 Hz amplitude modulation by 1000 Hz pitch, then 61% on 40 Hz amplitude modulation by 2000 Hz pitch. Finally, 57% of participants met criterion on the 80 Hz amplitude modulation by 2000 Hz pitch category. Table 2 breaks down the differences in percentage of people reaching criterion by group. People experiencing misophonia met criterion less than the control group on 3 out of the 4 stimuli. Notably, there is an 8.3 percentage point difference on the 40 Hz amplitude modulation by 2000 Hz pitch stimulus between groups.

Table 2

Percentage of participants reaching criterion

Amplitude modulation	Pitch	Percentage		
		Misophonia	Control	Total
40 Hz	1000 Hz	66.7	66.7	66.7
	2000 Hz	55.6	63.9	61.1
80 Hz	1000 Hz	61.1	63.6	63
	2000 Hz	55.6	58.3	57.4

Note. $N = 54$.

The number of trials necessary for individuals to meet criterion on each category was also assessed across group membership using a 2 (group) x 4 (category) repeated measures ANOVA. The assumptions for normality were met and tested using Mauchly's test of sphericity, $\chi^2(5) = 7.09$, $p = 0.21$. Again, there were no statistically significant findings. There was not a significant main effect of group membership, $F(1, 3) = 37.93$, $p = 0.33$. There was also no statistically significant difference in how many trials it took to reach criterion for each category, $F(1, 3) = 107.02$, $p = 0.37$. Finally, there was no statistically significant interaction between group and the amount of trials it took for each category to reach criterion, $F(1, 3) = 24.5$, $p = 0.87$ (Table 3).

Table 3

Repeated measures ANOVA table for trials to reach criterion

Source	Sum of Squares	*df*	Mean Square	*F*	*p*
Between-subjects effects					
Group membership	37.92	1	0.058	0.197	0.0778
Residuals	15.313	52	0.294		
Within-subjects effects					
Category	0.248	3	0.083	0.366	0.778

Category x Group membership	0.044	3	0.015	0.065	0.978
Residuals	35.215	156	0.226		

Note. $N = 54$.

Perseveration analyses

Lag distribution analysis

Inclusion for the lag distribution analysis and perseveration probability analysis required that a log file must have been created by the stimulus presentation software while completing the EEG session. Due to a technical error in saving log files, 11 participants were not included for these analyses. The final participant pool for all of the perseveration analyses included 43 participants. Lag distributions were created for each of these participants. Each lag was matched for every participant to create the observed distribution. A random distribution was created by shuffling each participant's distribution eighty times and calculated lags on each shuffled distribution. An average from each distribution for each lag was used to compose the final randomized distribution. Figure 3 includes the average lag distributions for each group. A χ^2 goodness-of-fit test was conducted between the observed distributions and random distributions for each participant, which yields 43 total χ^2 statistics. Table 4 includes each of the χ^2 statistics for the lag distributions created. There were 3 statistically significant χ^2 goodness-of-fit tests. They all consist of participants in the control group.

Table 4

χ^2 goodness-of-fit test for individual distributions

Group	Lag Distribution		Perseveration Probability	
	χ^2	*p*-value	χ^2	*p*-value

Control	4.62	0.866	3.78	0.925
Misophonia	14.99	0.091	**20.70**	**0.014***
Control	9.13	0.425	3.5	0.623
Control	5.38	0.800	2.5	0.776
Misophonia	11.55	0.239	13.06	0.160
Control	8.17	0.517	**20.82**	**0.013***
Control	3.42	0.945	2.167	0.950
Control	11.10	0.269	3	0.699
Misophonia	8.96	0.441	8.53	0.481
Control	7.50	0.585	2	0.572
Misophonia	15.93	0.068	15.29	0.083
Control	5.61	0.778	6.75	0.66
Control	4.93	0.840	6.57	0.681
Misophonia	10.64	0.301	8.94	0.443
Control	**19.88**	**0.019***	**23.43**	**0.005****
Control	8.33	0.501	3	0.558
Misophonia	5.11	0.825	7.13	0.623
Control	7.47	0.588	6.33	0.706
Control	9.50	0.392	8.83	0.453
Control	8.38	0.496	9.17	0.422
Control	6.00	0.740	12.17	0.204
Control	8.60	0.475	3.58	0.826
Control	10.54	0.309	12.88	0.168
Control	**17.22**	**0.045***	**23.42**	**0.005****
Control	16.54	0.056	12.95	0.165
Control	11.13	0.267	7.67	0.568

Control	10.81	0.289	7.25	0.403
Control	5.98	0.741	3.03	0.882
Misophonia	1.91	0.993	4.03	0.909
Misophonia	13.78	0.130	16.30	0.061
Control	15.71	0.073	12.39	0.192
Misophonia	7.72	0.563	11.54	0.241
Misophonia	9.11	0.427	7.92	0.543
Control	5.39	0.799	2.79	0.972
Control	**21.04**	**0.012***	15.44	0.079
Control	12.48	0.188	10.04	0.347
Misophonia	7.73	0.561	10.54	0.308
Misophonia	16.20	0.063	12.38	0.193
Control	10.95	0.279	5.92	0.748
Control	10.28	0.328	14.03	0.121
Control	12.97	0.164	15.34	0.082
Misophonia	9.05	0.433	6.5	0.370
Control	15.54	0.077	6	0.306

Note. *$p < 0.05$, **$p < 0.01$.

In order to evaluate the differences in perseveration behaviors between those who experience misophonia and the control group, the AUCs of the distributions were assessed. The area of interest is the absolute difference between the random distribution and the observed lag distribution. This absolute difference is taken for each participant. A *t*-test showed no difference in the AUC between the two groups, $t(41) = 1.16$, $p = 0.25$. Perseverative behaviors were also not seen through a *t*-test of the positive AUC between groups, $t(41) = 1.58$, $p = 0.12$.

Perseveration probability analysis

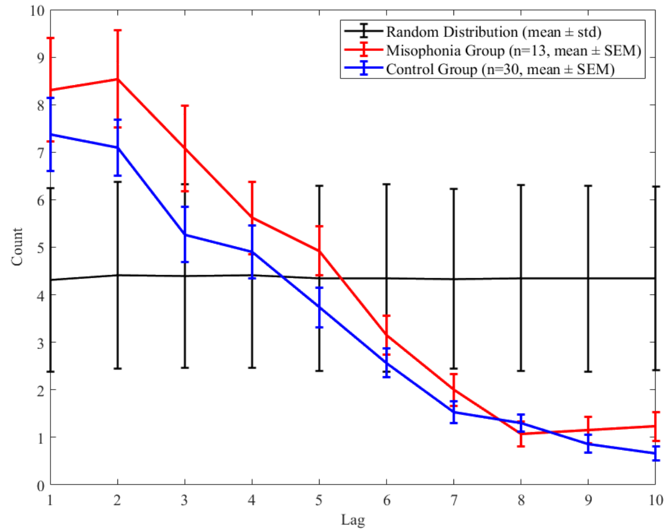
A similar approach was used to create the perseveration probability distribution. First, perseveration probability was calculated for every lag then converted to a percentage. A random distribution was made in a similar way as the lag distribution. A χ^2 goodness-of-fit test was run to determine whether there were differences between the perseveration probability distribution and the random distribution for every participant. Again, this results in 43 different distributions (see Table 4). The average perseveration probability distributions for each group are included in Figure 3. Using perseveration probability, 4 comparisons yielded a statistically significant χ^2 goodness-of-fit test. Of those 4, only one person experienced misophonia. The three LDA distributions that were significant also yielded significant PPA distributions.

Again, to observe group level differences in the perseveration probability, AUC on individual distributions was assessed. An absolute difference between the perseveration probability distribution and the expected distribution for every individual was taken. Further, the positive AUC was assessed to examine differences in specifically perseveration behaviors between groups. A *t*-test revealed no group differences in AUC for perseveration probability, $t(41) = 1.06$, $p = 0.30$. The positive AUC also revealed no differences in perseveration behavior, $t(41) = -0.18$, $p = 0.86$.

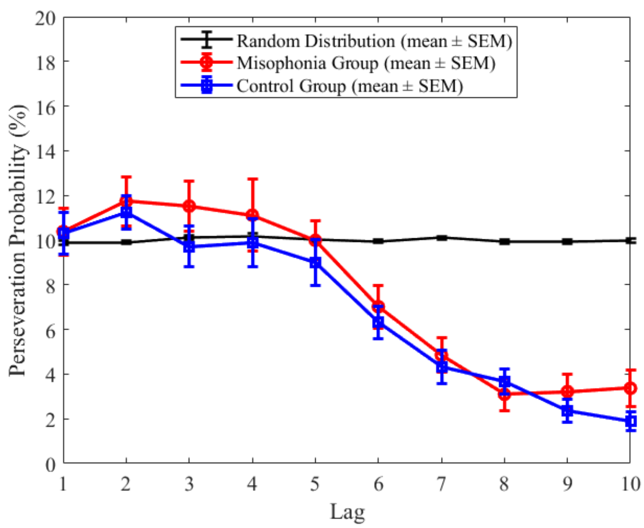
Figure 3

Group differences in LDA and PPA

A



B



Note. (A) Average lag distributions separated by group membership. **(B)** Average perseveration probability distributions separated by group membership.

Inter-trial coherence correlations

Inter-trial coherence was analyzed for three neural variables of interest: stimulus onset, 40 Hz collapsed across tone, and 80 Hz collapsed across tone. These variables were then correlated to the learning behaviors collected in this study: trials to criterion and meeting criterion. There were no significant correlations between the neural variables and the behavioral variables (see Table 5). The area under the curve difference for the lag distributions and perseveration probability distributions were also correlated. The lag distribution AUC was positively correlated with 40 Hz ITC, $r(43) = 0.341$, $p = 0.027$. Lag distribution AUC was negatively correlated with trials to criterion for the 40 Hz amplitude modulation by 1000 Hz pitch stimulus, $r(43) = -0.403$, $p = 0.007$. Trials to criterion for the 40 Hz amplitude modulation by 1000 Hz pitch stimulus was also negatively correlated with perseveration probability AUC, $r(43) = -0.388$, $p = 0.01$. Both perseveration probability distribution, $r(43) = -0.347$, $p = 0.022$, and lag distribution, $r(43) = -0.323$, $p = 0.035$, AUCs were negatively correlated with trials to criterion for the 80 Hz amplitude modulation by 1000 Hz pitch stimulus. Correlations were split by group membership to further explore these relationships. Table 6 shows that the correlation that remained significant for the control group is between trials to criterion for the 40 Hz amplitude modulation by 1000 Hz pitch stimulus and the perseveration probability distribution AUC, $r(30) = -0.363$, $p = 0.048$. None of the correlations observed across groups remained significant for those who experience misophonia; however, the direction of the effect remained the same (Table 7). The lack of significance may be due to the reduction in sample size. Interestingly, there were medium-sized negative correlations with the lag distribution, $r(13) = -0.512$, $p = 0.073$, and perseveration probability, $r(13) = -0.511$, $p = 0.075$, AUCs and trials to criterion for the 40 Hz amplitude modulation by 1000 Hz pitch stimulus, though they are not statistically significant. A similar outcome was seen for the trials to criterion for the 80 Hz amplitude modulation by 1000 Hz pitch stimulus but only for the lag distribution AUC, $r(13) =$

-0.509, $p = 0.076$. 40 Hz ITC did negatively correlate with 80 Hz amplitude modulation by 1000 Hz pitch stimulus for this group as well, $r(18) = -0.479$, $p = 0.044$.

Table 5

Pearson's Correlations across groups

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Onset ITC	-												
2. 40 Hz ITC	-0.068	-											
3. 80 Hz ITC	0.214	-0.036	-										
4. 40 Hz x 1000 Hz Trials to Criterion	-0.141	0.005	-0.080	-									
5. 80 Hz x 1000 Hz Trials to Criterion	0.036	-0.063	0.192	-0.148	-								
6. 40 Hz x 2000 Hz Trials to Criterion	-0.057	-0.176	0.209	-0.086	**0.314***	-							
7. 80 Hz x 2000 Hz Trials to Criterion	0.031	-0.100	-0.019	0.171	0.004	0.011	-						
8. 40 Hz x 1000 Hz Reaching Criterion	0.129	-0.108	0.022	**-0.531*****	0.245	0.043	-0.243	-					
9. 80 Hz x 1000 Hz Reaching Criterion	0.002	-0.073	0.159	0.181	**-0.587*****	-0.170	0.138	-0.242	-				
10. 40 Hz x 2000 Hz Reaching Criterion	0.149	-0.187	0.160	0.105	-0.019	**−0.5130*****	0.228	0.108	0.175	-			
11. 80 Hz x 2000 Hz Reaching Criterion	0.016	-0.096	0.074	-0.099	-0.004	0.005	**-0.583*****	**0.344***	-0.149	0.192	-		
12. LDA Area Under Curve	−0.071	0.297	-0.080	**-0.403****	-0.181	**-0.323***	-0.156	0.094	0.063	-0.024	-0.207	-	
13. PPA Area Under Curve	-0.086	**0.341***	-0.119	**-0.388***	−0.108	**-0.347***	-0.148	0.128	-0.005	0.010	-0.215	**.966*****	-

Note. *$p < 0.05$, **$p < 0.01$, *** $p < 0.001$.

Table 6

Pearson's Correlations for control group

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Onset ITC	-												
2. 40 Hz ITC	0.130	-											
3. 80 Hz ITC	0.334	0.012	-										
4. 40 Hz x 1000 Hz Trials to Criterion	-0.033	-0.043	-0.083	-									
5. 80 Hz x 1000 Hz Trials to Criterion	-0.131	-0.073	0.226	-0.144	-								
6. 40 Hz x 2000 Hz Trials to Criterion	-0.183	-0.044	0.185	-0.287	**0.750*****	-							
7. 80 Hz x 2000 Hz Trials to Criterion	-0.091	-0.220	0.047	0.292	0.086	0.057	-						
8. 40 Hz x 1000 Hz Reaching Criterion	-0.006	-0.296	0.042	**-0.568*****	0.286	0.240	-0.308	-					
9. 80 Hz x 1000 Hz Reaching Criterion	0.200	-0.117	0.256	0.246	**-0.499*****	-0.321	0.216	-0.286	-				
10. 40 Hz x 2000 Hz Reaching Criterion	0.234	-0.318	0.258	0.308	-0.208	**−0.425*****	0.207	-0.041	**0.398***	-			
11. 80 Hz x 2000 Hz Reaching Criterion	0.196	-0.075	0.087	-0.198	-0.071	0.019	**-0.535*****	0.359*	-0.166	0.186	-		
12. LDA Area Under Curve	−0.057	0.304	-0.017	**-0.363***	-0.340	-0.295	-0.052	-0.008	0.046	-0.023	-0.284	-	
13. PPA Area Under Curve	-0.044	0.340	-0.105	-0.329	−0.277	-0.276	-0.051	0.010	-0.023	-0.027	-0.291	**.965*****	-

Note. *$p < 0.05$, **$p < 0.01$, *** $p < 0.001$.

Table 7

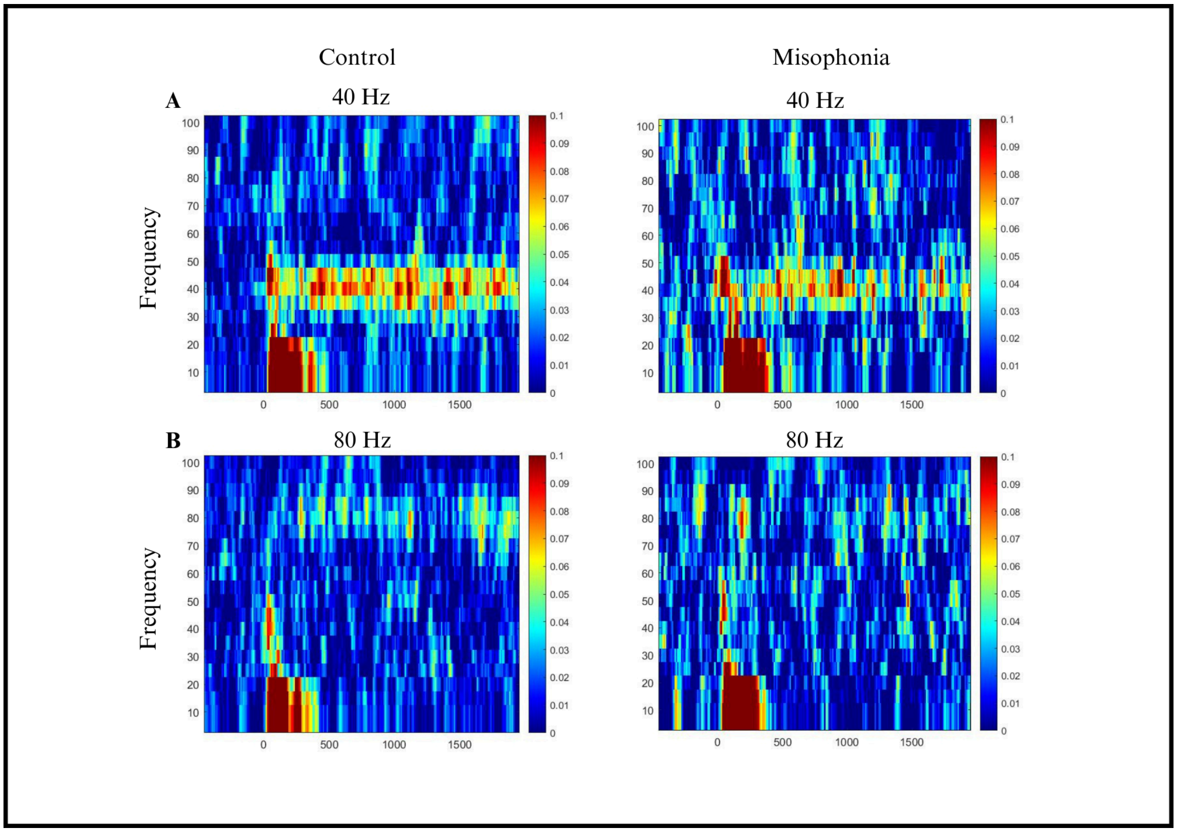
Pearson's Correlations for participants with misophonia

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Onset ITC	-												
2. 40 Hz ITC	-0.346	-											
3. 80 Hz ITC	0.202	-0.309	-										
4. 40 Hz x 1000 Hz Trials to Criterion	-0.301	0.124	-0.043	-									
5. 80 Hz x 1000 Hz Trials to Criterion	0.172	-0.025	0.212	-0.180	-								
6. 40 Hz x 2000 Hz Trials to Criterion	0.083	**-0.479***	0.333	0.256	0.444	-							
7. 80 Hz x 2000 Hz Trials to Criterion	0.107	0.185	-0.160	-0.045	-0.185	-0.063	-						
8. 40 Hz x 1000 Hz Reaching Criterion	0.293	0.350	-0.035	**-0.496***	0.171	-0.351	-0.123	-					
9. 80 Hz x 1000 Hz Reaching Criterion	-0.174	0.013	-0.209	0.086	**-0.743*****	0.089	0.025	-0.158	-				
10. 40 Hz x 2000 Hz Reaching Criterion	0.085	0.109	-0.186	-0.258	0.348	**–0.675*****	0.284	0.403	-0.255	-			
11. 80 Hz x 2000 Hz Reaching Criterion	-0.156	-0.158	0.001	0.086	0.132	-0.020	**-0.677*****	0.316	-0.125	0.204	-		
12. LDA Area Under Curve	0.022	0.221	-0.308	-0.511	0.206	-0.394	-0.355	0.437	0.119	-0.063	-0.035	-	
13. PPA Area Under Curve	-0.032	0.309	-0.373	-0.512	0.249	-0.509	-0.300	0.472	0.046	0.059	-0.072	**0.975*****	-

Note. **p* < 0.05, ***p* < 0.01, *** *p* <0.001.

Figure 4

ITC plots



Note. Stimulus onset is seen on each of the ITC plots at zero on the y-axis. **(A)** ITC plots for control and misophonia groups on the 40 Hz stimulus collapsed across tone. **(B)** ITC plot for control and misophonia groups on the 80 Hz stimulus collapsed across time.

Discussion

Misophonia is a complex condition that can negatively affect the daily lives of people who experience it. To effectively treat misophonia, the research community needs to come to a consensus about the aspects that uniquely make up misophonia. There has been much debate about how to categorize the condition. Misophonia is currently not included in the DSM; research aiming to understand the underlying mechanisms of the condition and diagnostic criteria is still underway. Researchers have suggested that misophonia should be classified as a unique mental disorder; these efforts have been accompanied with work trying to clarify diagnostic criteria (Schröder et al., 2013, 2014). Other researchers have considered misophonia a syndrome (Brout et al., 2018; Cassiello-Robbins et al., 2021; Wu et al., 2014). Norris et al. (2022) found significant differences in the clustering solutions between those who experience severe misophonia and those who may experience one or two presentations of misophonia symptoms. This may indicate that misophonia may be syndromic, which includes a range of symptoms and severity that must be accounted for, rather than a neat diagnosis. Jasterboff and Jasterboff, who coined the term 'misophonia', consider it a component of decreased sound tolerance that may typically accompany more complex issues (2001).

The main aim of this study was to explore the neuropsychological aspects of misophonia to gain a wider conceptualization of the disorder. Recent research has found a deficit in sensory processing of auditory stimuli for those with misophonia. Specifically, individuals with misophonia show a diminished N1 response, an EEG measure of stimulus registration, compared to controls (Schröder et al., 2014). Regarding cognitive differences in misophonia, the findings from Eijsker et al. (2019) show that those with misophonia display an accuracy-over-speed response bias. This implied a potential behavioral rigidity reminiscent of a compulsion. In an effort to replicate recent findings, behavioral rigidity was expected to be displayed through differences in the trials it takes to reach criterion for those with misophonia, and perseveration through LDA and PPA. First, behavioral rigidity was not displayed in this sample. The learning behavior of meeting criterion on each category was not significantly different from controls. The percentage of people reaching criterion on each stimulus was assessed in order to investigate whether participants were indeed reaching criterion on at least some stimuli. Table 2 shows the differences in reaching criterion for each category by group. Interestingly, there was a smaller percentage of those with misophonia reaching criterion on 3 of the 4 categories. A larger difference between groups on the 40 Hz amplitude modulation by 2000 Hz pitch was found, although this difference is not enough to drive a significant category by group interaction. Behavioral rigidity impacting learning speed was also not displayed across group membership in this sample. There was no statistically significant difference in how many trials it took participants to reach criterion across group membership.

Previous research has not found perseverative behavior in those with misophonia utilizing a visual task (Abramovitch et al., 2024; Frank et al., 2020; Gokovali Begenen, 2023). To explore perseverative behaviors in an auditory sensory environment that may be more relevant to the auditory features of misophonia, an auditory learning task that performs similarly to the Wisconsin Card Sorting Test was developed and used here. The perseveration behaviors that were anticipated were not seen in this sample. Individual lag distributions showed that primarily a small number of participants in the control group displayed perseverative behaviors. Both absolute and positive AUCs also showed no significant group differences in lags.

Perseveration probability analysis was used to analyze perseveration across time. One additional participant displayed perseveration via the PPA χ^2 goodness-of-fit test; this was the only participant who experienced misophonia who showed evidence of perseveration. Again, absolute and positive AUCs indicated that there was no evidence of group-level differences in preservation utilizing PPA. While the group-level differences that were expected were not evident in this sample, analyzing perseverative behaviors through individual distributions highlighted the individual differences that exist in perseverative behaviors.

A relationship between sensory processing fidelity and learning behaviors was expected. There were no strong relationships between stimulus sensory processing, namely at stimulus onset, 40 Hz, or 80 Hz both collapsed across tone, with the amount of trials to reach criterion or reaching criterion. There was a positive correlation between the lag distribution AUC and the 40 Hz stimulus sensory fidelity. This finding may indicate that more accurate stimulus processing actually contributes to more perseverative behaviors, or may be a function of slight group differences in stimulus processing fidelity. There were also negative correlations between the perseverative measures and the amount of trials to reach criterion for both the 40 Hz amplitude modulation by 1000 Hz pitch and the 80 Hz amplitude modulation by 1000 Hz pitch stimuli. To examine these relationships further, correlations were split by group.

The only correlation observed across groups that remained significant after separating by group was between the number of trials needed to reach criterion for the 40 Hz amplitude modulation at a 1000 Hz pitch stimulus and AUC for the perseveration probability distribution in the control group. This suggests that participants who showed more perseverative behavior required fewer trials to meet the criterion, possibly reflecting better stimulus processing. Though not statistically significant, similar negative correlations were observed in the misophonia group: the AUCs for both lag and perseveration probability distributions were negatively correlated with trials to criterion for the 40 Hz amplitude modulation by 1000 Hz pitch stimulus. Interestingly, the 40 Hz ITC was significantly negatively correlated with the amount of trials to reach criterion on the 40 Hz amplitude modulation by 2000 Hz pitch stimulus. This correlation was anticipated, as it indicates that those who had higher stimulus fidelity were able to reach criterion in less trials.

These correlations, although mostly not significant for the misophonia group, may reflect differences in processing. Sensory processing fidelity measured through auditory N1 response also found that those with misophonia have differences in auditory processing (Schröder et al., 2014). Specifically, it is suggested that those with misophonia have diminished auditory information. The relationship between the ITC measures and learning behaviors may not have been statistically significant for the control group or across groups potentially because the controls may have reached a ceiling on their sensory processing fidelity. The absence of statistical significance in the misophonia group for the other correlations discussed might stem from the smaller sample size in this group. However, the data could indicate that individuals with misophonia perseverate less while requiring more trials to reach criterion, suggesting potentially weaker stimulus processing compared to the control group. This pattern might imply that individuals with misophonia are compensating for reduced sensory fidelity by focusing more intently on the stimuli, leading to reduced perseverative behavior. Still, further investigation is required to determine whether this reflects a response bias, as suggested by prior research (Eijsker et al., 2019). Future research should examine this relationship in more detail to better understand how these variables interact.

There may be several reasons why the outcomes that were anticipated were not found in this study. First, the task may have been too difficult for people to learn the rules. Participants were expected to learn and reach criterion before 10 minutes elapsed. There were 4 stimuli, with two volumes added as distractors. The volumes added an additional challenge that was harder for participants than anticipated. If participants were not effectively learning the task, it would be hard to capture perseverative behaviors. In previous research investigating perseverative behavior, participants were presented far more trials than what was collected for this study (Cohen, 1998). Missing data from technical problems with behavioral recordings randomly but disproportionately affected the misophonia group, leaving 30 controls and only 13 individuals with misophonia in the lag distribution, perseveration probability, and ITC analyses. This likely impacted statistical power for the differentiating groups on those metrics.

Misophonia was tested for in this sample in a number of different ways. First, participants were asked if they experience misophonia during the audiology workup. They also completed the MQ Misophonia Severity Survey, which was used as the final inclusion criteria in this study, consistent with previous work utilizing the MQ (Abramovitch et al., 2024; Cassiello-Robbins et al., 2021; Daniels et al., 2020; Frank et al., 2020; Norris et al., 2022). However, there were some participants who indicated that they experienced misophonia but were not in the misophonia group in this sample as they did not reach the threshold on the MQ. The lack of diagnostic criteria makes it so that there is flexibility and subjectivity in the inclusion criteria for those who experience misophonia. There is debate in the research on how to threshold for misophonia, but there is no clear guideline. Some research has been conducted using self-reporting measures to indicate experiencing misophonia (T. H. Dozier & Morrison, 2017; Rouw & Erfanian, 2018; Schröder et al., 2013; Wu et al., 2014); however, any researchers use surveys that have been developed to specifically gauge misophonia experiences (Abramovitch et al., 2024; Daniels et al., 2020; Kumar et al., 2021; Norris et al., 2022). There is no consistency in the survey that is being used as inclusion criteria across the body of work in misophonia. Pure-tone thresholds and loudness discomfort levels have been used as audiological assessments of misophonia (P. J. Jastreboff & Jastreboff, 2013, 2015). Research in misophonia would greatly benefit from having clear criteria for diagnosis based on objective behaviors; this would reduce subjectivity in the inclusion criteria for group membership. This may lead to clearer research outcomes, suggestions, and implications. Simply, a survey or an audiology workup cannot accomplish what a psychometrically-sound psychiatric test can. Based on the findings from the current study, objective behaviors related to perseveration in the presence of auditory stimuli are not likely candidates for inclusion in a novel test for misophonia.

Utilizing neuropsychology may be a more well suited approach to understanding misophonia. The findings of this study, along with recent findings in misophonia, indicate that the condition may be highly individualized and potentially trigger specific. Future research may consider utilizing EEG data to evaluate how feedback is responded to for those with misophonia. Specifically, reaction time on future trials may be longer if given negative feedback. This relationship is also mediated by the anterior cingulate cortex, which slows down responses once given negative feedback (Van Den Bos et al., 2009). Other cognitive functions that have been considered in previous research include behavioral flexibility utilizing a Stroop task in a highly emotionally-valenced environment. Testing behavioral flexibility in this environment indicated that those with misophonia exhibited a greater Stroop effect than the controls (Daniels et al., 2020). Symptomology of misophonia was also presented in a continuum with a range of severity. Norris et al. (2022) also found a clustering effect of symptom severity in misophonia. This study was not a true ‘hot’ environment to test for perseveration. Utilizing an auditory task was meant to create a sensory ‘hot’ environment while not evoking an emotionally ‘hot’ environment. However, decoupling sensory from emotional “triggers” may not be effective as misophonia includes an emotional element. This may indicate that typical thresholding criteria as used in the DSM may not be an appropriate way to assess misophonia presence on its own. Additionally, the sample used in this study did not include many severe cases of misophonia. The suggestion that deficits in executive functioning may be trigger specific or requires a 'hot' environment may apply to all cases of misophonia or specifically those with moderate cases. General deficits in executive function may be expected for more severe cases; however the sample used here does not have enough severe cases to differentiate between them.

Conclusion

This study did not support any of the expected outcomes. First and foremost, perseveration was tested using an auditory learning task. This is a novel way of testing perseveration in misophonia. Based on the findings from this study, perseveration is likely not a behavioral concern for those with misophonia, regardless of the sensory modality. While some relationships were found between sensory processing fidelity and perseverative behaviors, these relationships do not follow expected patterns and thus will require additional study and replication to determine their significance, if any. Future studies would benefit from longer task times with additional trials, to allow for more individuals to reach criterion and potentially separate measures of learning success more effectively. Additionally, the current study suggests that auditory processing of typical sounds is not enough to impact behavior in misophonia; it is potentially not "hot" enough. Incorporation of truly "hot" environments for individuals with misophonia to investigate not just the impact of auditory processing, but also the impact of emotionally stimulating auditory triggers on executive function, may further elucidate whether trigger-related behaviors are related to highly circumscribed deficits in executive function.

Testing for cognitive differences in a ‘hot’ environment may clarify the level of symptom severity where these differences may potentially become more generalizable.

This study offers insight into this complexity by revealing that misophonia may not impair cognitive processes in the manner previously expected. These findings suggest that, despite some symptomatic overlap with other mental disorders, misophonia may follow a distinct profile that is highly individualized. Rather than mirroring the cognitive impacts observed in related conditions, misophonia may influence behavior through unique sensory pathways. The discussion of how to classify misophonia includes the need for distinction between misophonia and potential co-occurring conditions and the etiology of the condition in order to have clear criteria to assess the presence of misophonia in individuals and, most importantly, to have effective treatment protocols for people who experience the condition.

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